Design and Analysis of a Wireless Telemetry System Utilizing IEEE 802.16

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TABLE OF CONTENTS

1. Introduction 3

1.1 Motivation 3

2. System Selection 3

2.1 IEEE 802.16 Standard 5

2.2 Redline Equipment 6

2.3 Link Budget 9

3. Test Bed 10

3.1 Test Bed Objectives 10

3.2 Test Bed Architecure 11

3.3 Hardware Selection 13

3.4 Software Selection 14

4.Test Procedure 19

5. Test Results 23

5.1 Packet Size Effects 23

5.2 Received Signal Strength Effects 25

5.3 Additive Noise Effects 25

5.4 Interference Effects 25

5.5 Long Range Tests 28

6. Conclusions 30

Glossary 31

Appendix 1: VB Script 33

Appendix 2: Iperf Commands 35

Appendix 3:Redline Data sheet 39

Appendix 4:IP Traffic Data Sheet 41

Appendix 5:Radio Test Plan 43

1. Introduction

1.1 Motivation: Advanced Acoustic Concepts (AAC) has several projects that require a communications link between remote sites. The distances and data rates vary from project to project, but they desire a solution that can handle many of their needs by using standards based off the shelf equipment that can easily be deployed. To be quickly and cost affordable to deploy a wireless system was determined to be necessary. This also affords the possibility to support mobile and nomadic units that can be connected very easily with out the need for highly trained technicians. AAC is experienced at using COTS (consumer off the shelf) components to meet the needs of military subsystems. The benefits of using COTS components are that the economics and availability are very good related to custom hardware. The cost and time of development is also kept to a minimum. The goal of this project was to identify equipment that is commercially available that would meet the telemetry needs of AAC, and then do lab testing and a field test to do a proof of concept on both the product and the standard that it is based upon.

The ideal telemetry system to meet all of the needs of AAC would provide a data rate of 50Mbps at a range of 50 miles. No system that was investigated was able to simultaneously meet both requirements. 20 Mbps at a range of 20 miles was chosen to be an appropriate goal with the current state of consumer products.

To complete this task the first step is to identify appropriate standards and to see what the capabilities of current systems are. The next step is to design a test bed that would allow for testing of the equipment. The testing then has to be carried out and the results analyzed.

2. System Selection

In order to gather information on what products were commercially available research was done both through the Internet and through meeting with vendors at the 2004 CTIA wireless conference. At this conference several vendors were contacted and their product lines were

discussed. It became clear that the emerging IEEE 802.16 standard was the standard that best met the criteria of the task.

The top contending systems on the basis of being 1) standards based 2) long range capable and 3) capable of throughput in excess of 40Mbps were the Redline Communications and Airspan offerings. Technically the two systems were very similar in every aspect. The table in Figure 1.1 shows how similar the two systems are in the basic system specifications. Redline Communications' AN-50 was chosen as the system to acquire and test at length. They have demonstrated high reliability and high throughput links in cellular back haul deployments. This experience made them a strong candidate. Although the IEEE 802.16 standard had not been finalized at the time these products were obtained they were engineered with the standard in mind and use the same modulation formats, so the results are suitable for a proof of concept demonstration.

Type	Encryption	Tx	Rx	BW	Bit Rate	Range	Interface	Freq
Redline AN50 OFDM P-P, P-MP www.redlinecommunications.com	Yes, 64 bit Proprietary	-20 to + 20 dBm	- 86 dBm (6 Mb/s)	20 MHz	48 Mb/s at Ethernet port	50 M, LOS 6 M, NLOS	Ethernet, Bridge 10/100 base-T	5.8 GHZ unlicensed
Airspan AS3030 www.airspan.com	Yes, DES	20dBm	-86 dBm (6 Mb/s)	20 MHz	49 Mb/s full duplex	48 M, LOS	Ethernet bridge 4 10/100 Base-T ports	5.8 GHz unlicensed

Radio System	IP Support	Power Consumption	Dimensions	Weight	Antenna Weight	Antenna Gain	Temperature Ranges
Redline AN50	Bridge	48 VDC 39W	43.2cm X 305cm X 44.5cm	2.0kg+1.0kg	5.0kg 7.0kg	28dBi 17dBi	0-55C -40 - + 60C
Airspan AS4030	Bridge	24-70 VDC 39W	43.2cm X 305cm X 45cmb	~3.0kg	5.0kg 7.0kg	28dBi 17dBi	0-55C -40 - + 60C

Figure 1.1 A comparison of the Redline AN-50 and the Airspan AS3030. Both systems are very similar and they were the top two candidates considered for further testing.

2.1 IEEE 802.16 Standard: The IEEE 802.16 standard is designed as the air interface for wireless metropolitan area networks (MANs). A wireless MAN provides a radio connection between an exterior mounted antenna on a building and a central base station. The MAN is used as a replacement for a wired access network such as cable, DSL, or fiber optic cable. The ability to connect sites with out an expensive infrastructure between them can provide economic advantages as well as advantages in ease of deployment. Although proprietary systems have been deployed before, a standard has never before existed that would allow for product interoperability and consequently the price drop that is associated with widespread competition and deployment.

The 802.16 standard does not specify a frequency that must be used, but instead breaks the spectrum into two separate sections: 2-11GHz and 11-66GHz. This paper will only deal with the 2-11 GHz portion of the spectrum, as that is the frequency set in which most of the equipment is available. At higher frequencies it becomes more difficult to get very long-range links, as the path loss is frequency dependent. IEEE 802.16 can be implemented in both licensed and unlicensed bands. The use of unlicensed spectrum is appealing since it saves the cost of getting a license and allows for deployment in a wide geographic range with out the need for licensing.

The IEEE 802.16 medium access control (MAC) was designed with very high bit rates in mind, in both the uplink and down link directions. Access and bandwidth allocation must be able to handle multiple different data streams as well as different quality of service (QoS) requirements. Quality of service requirements may be such that one link has priority over another link when there is bandwidth contention. Quality of service also dictates what the maximum throughput of a link is limited to. This is useful for fixed broadband wireless providers to have a flexible way to serve different types of customers. The 802.16 MAC provides a wide range of service types analogous to ATM systems.

Each user is given a burst profile that specifies the modulation and coding format to be used for that user. By adjusting the burst profile the MAC can make use of high data rate and highly spectrally efficient modulation schemes and still have the ability to scale back to a lower bit rate and more robust modulation format so that the link can sustain very high availability, with out

sacrificing performance. 99.999 percent link availability is planned into the standard. By making these adjustments the throughput on the link is always maximized for the given conditions. This "self tuning" of the link will provide for the ability to quickly establish links with out having to manually adjust the equipment.

In the 2-11 GHz frequencies the MAC layer also issues automatic repeat requests (ARQ) to insure higher data reliability. The MAC also includes a privacy sub layer that provides authentication of network access and connection establishment to avoid theft of signal. Encryption and key exchange are also built into the MAC for added security.

Orthogonal frequency division multiplexing (OFDM) is used in the unlicensed bands with the media access being by time division multiplexing. The system is also time division duplex. This makes for efficient use of the spectrum in that the up and down links can be asymmetric with no loss of efficiency. The use of OFDM also has the effect that each of the OFDM signals occupies a narrow bandwidth. This loosens the requirement for coherence bandwidth considerably, and helps with the problems of time domain dispersion caused by multipath interference.

2.2 Redline Equipment: For the purpose of these tests Redline AN-50 radios were purchased. 64 QAM modulation is an option on these radios; it brings the advertised throughput up to 48Mbps measured at the Ethernet port. This option was purchased on three of the radios. A total of four radios were purchased so that point to point operation could be tested, as well as point to multipoint operation. The point to multipoint testing did not get completed, as there was a hardware problem on the base station terminal that has to be resolved under warranty. The four modulation types that are implemented in the AN-50 are BPSK, QPSK, 16 QAM and 64 QAM. The AN-50 radios include a forward error-correcting scheme that is identified by the number of data bits to the total number of bits. For example a ¾ code would contain 3 bits of data for every 4 bits transmitted. The other bit is used for error correction purposes. The coding rate is varied along with the modulation format to provide the highest level of throughput possible. The table below shows the various settings for modulation type and coding scheme that are used in the AN-50 radios, along with the data rates that are achievable for each.

Modulation	Coding Rate	Over The Air Rate (Mbps)	Uncoded Burst Rate (Mbps)	Average Ethernet Rate (Mbps)
BPSK	½	12	6	5.82
BPSK	¾	12	9	8.63
QPSK	½	24	12	11.38
QPSK	¾	24	18	16.7
16 QAM	½	48	24	21.77
16 QAM	¾	48	36	33.01
64 QAM	⅔	72	48	44.1
64 QAM	¾	72	54	48.8

Figure 2.1 Throughput for various modulation schemes. The over the air throughput is much higher than the Ethernet rate since it also includes added bits for error detection and link layer retransmission, as well as link management.

The AN-50 radios operate in the 100MHz available in the 5.8GHz unlicensed band. Each radio link occupies one 20 MHz wide channel. The spectrum is broken into 9 partially overlapping channels. Two radio links in close proximity should be separated by 20MHz to avoid co-channel interference. The table in Figure 2.2 below shows the center frequencies of the 9 channels.

Channel	Frequency
1	5735 MHz
1A	5745 MHz
2	5755 MHz
2A	5765 MHz
3	5775 MHz
3A	5785 MHz
4	5795 MHz
4A	5805 MHz
5	5815 MHz

Figure 2.2 Channel Frequency Assignments.

The AN-50 functions as a wireless Ethernet bridge. For all of the testing the IP addresses of the two radios were set to 192.168.25.2 and 192.168.25.4. The subnet mask was set to 255.255.255.0. The computers hooked to the terminals were given IP addresses of 192.168.25.100 and 192.168.25.200. The subnet mask was the same as for the terminals themselves. The Redline radios are capable of issuing flow control frames. This feature is very nice for use with UDP traffic. When the radio runs out of resources it is able to issue a pause frame to the Ethernet devices attached to it. Once resources are again available a resume frame is transmitted and traffic flows again. The AN-50 runs out of resources because the Ethernet side is 100Mbps Ethernet but the RF side can only support 48Mbps maximum. Without flow control data would be discarded at the input to the radio at a rate of 52 (100-48) Mbps. The complete system specifications are shown below in Figure 2.3.

AN-50 System Specifications

System Capability	Non-line-of-sight operations, PTP mode								
RF Band	5.725 - 5.825 GHz (unlicensed Band)								
Channel Center Frequencies	Channel	1	1A	2	2A	3	3A	4	4A	5
	Freq.	5.735 GHz	5.745 GHz	5.755 MHz	5.765 GHz	5.775 GHz	5.785 GHz	5.795 GHz	5.805 GHz	5.815 GHz
Channel Size	20 MHz									
RF Dynamic Range	> 50 dB									

Modulation/Throughput	Modulation	Coding Rate	Over The Air Rate (Mbps)	Uncoded Burst Rate (Mbps)	Average Ethernet Rate (Mbps)
	BPSK	½	12	6	5.82
	BPSK	¾	12	9	8.63
	QPSK	½	24	12	11.38
	QPSK	¾	24	18	16.7
	16 QAM	½	48	24	21.77
	16 QAM	¾	48	36	33.01
	64 QAM	⅔	72	48	44.1
	64 QAM	¾	72	54	48.8

Maximum Tx Power	-20 to +20 dBm (region specific) *
Rx Sensitivity	-86 dBm at 6 Mbps
IF Cable	• Maximum length up to 250 ft (76m) using RG6U / 500 ft (152m) using high-grade RG11U • Maximum allowable losses at 2.5 GHz: RG6: 10 dB/30m (100 feet) at 25°C RG11: 5 dB/30m (100 feet) at 25°C • Multiplexed IF, DC power, control (Tx/Rx, AGC, APC)
Network Attributes	• Transparent bridge • DHCP passthrough • VLAN passthrough • 802.3x Ethernet flow control • 802.1p Network traffic prioritization
Modulation	Dynamic Adaptive Modulation (bi-directional) auto selects: • BPSK • QPSK • 16 QAM • 64 QAM
Over The Air Encryption	Proprietary 64-bit encryption
Coding Rates	1/2, 3/4 and 2/3
MAC	• Point to point • Automatic Repeat Request (ARQ) error correction • Concatenation/Fragmentation
Range	• Over 10 km / 6 miles non-line-of sight • Over 80 km / 50 miles line-of-sight
Network Services	Transparent to 802.3 services and applications
Duplex Technique	Dynamic TDD (time division duplex)
Wireless Transmission	OFDM (orthogonal frequency division multiplexing)
Backhaul Connection	10/100 Ethernet (RJ45)
System Configuration	• Web interface and SNMP • CLI via Telnet and Local Console Port

Fig. 2.3 Redline AN-50 System Specifications

2.3 Link Budget Consideration: A link budget for the Redline radio was considered for the distance of 20 miles. The system was considered with 28dBi panel antennas and a transmit power of 20dBm. The free space path loss of a 5.8GHz signal at a distance of 20 miles is calculated by the equation PL = $\frac{(\lambda^2)}{(4\pi)^2(d)^2}$ =138 db. The receive power is then 20+28+28-138 = -62dbm. The receive sensitivity of the AN-50 is specified as being –86dbm, therefore the link margin is 24db. This margin is necessary to account for other losses not considered in the ideal case calculated above. Losses can be occurred in the antenna cable connecting the transceiver to the antenna, as well as pointing losses due to the antennas not being exactly aligned with each other. The link margin is also a buffer against seasonal impairments that may occur such as heavy rain and seasonal foliage obstruction.

For the Redline equipment it is important to note that the received sensitivity of –86dbm is the received power necessary to complete a BPSK link. To achieve the higher order modulations a larger received signal strength is required. This is tested and the experimental results are shown in Figures 5.2 and 5.3. If a higher order modulation is desired to achieve a higher throughput refer to those graphs to infer the received signal power necessary and use that as the receiver sensitivity was used above.

3.Test Bed

3.1 Test Bed Objectives: A test bed for evaluating a high-speed radio link is required. This test bed should be able to simulate a real world link and as many of the parameters that a real world system has to face as possible. The test bed also has to be able to generate and monitor the traffic on the link.

The link that is to be tested is a high speed RF link between remote terminals. Each terminal accepts standard RJ-45 Ethernet inputs and has an IF output that goes to a transceiver unit that up converts to the 5.8GHz band. This output has a standard N-type male connector. The antenna connects to this port. In lab based testing the antennas weren't used, but instead the RF ports on the transceivers were connected together with cables, running through other equipment as necessary.

The test bed had to be able to do testing of throughput vs. received signal strength, throughput vs. signal to noise and distortion ratio, throughput vs. packet size, as well as throughput as a function of configuration settings on the terminal itself.

The RF portion of the test bed had to be able to allow for easy reconfiguration of the test configuration. The test bed had to be able to create values of added noise, loss, and interference that would be able to simulate different types of link conditions. The noise value should range from thermal up to a value that makes the link inoperable. Loss had to be able to be variable so that the input power of the receive transceiver could be varied between the extremes of saturation and minimum sensitivity. Both the noise and the loss should be finely adjustable, on the scale of 1-db steps. Interference should be adjustable as well so that strong and weak interferers could both be simulated.

The interconnects for the test bed had to be able to meet certain requirements as well. The RF interconnects had to be able to have a low loss at the operating frequency of 5.8GHz. This is so that the loss over the cable itself is negligible compared to the other losses in the system. High

quality of shielding was required so that there would be minimum leakage of RF power. This insures that the energy is flowing through the test bed as designed, rather then having radiation leakage that may interfere with another portion of the test bed circuit. The IF interconnects have to be shielded as well, but the low frequency makes it much less critical. The loss on the IF cable is not important since the gain of the transceiver is adjusted to compensate for the cable loss. To connect the terminals to other computer equipment via Ethernet only required the use of standard 100Mbps cables.

Connected to each terminal we required a device to be able to send and receive IP traffic. This requires both a PC with a capable Ethernet card as well as some form of traffic generation software. The software also needed to be able to keep statistics on the amount of throughput that is flowing through the system.

The last requirement of the test bed was to have some way to observe and record the system parameters that the host terminals see. This is useful in verifying that the test bed is operating in a reasonable manner.

3.2 Test Bed Architecture: The test bed architecture needs to be flexible so that different link conditions can easily be simulated and tested. The basic architecture is shown below in Fig 3.1. This figure shows that a PC is connected on each end of the link. These then connect to the AN-50 terminals, which in turn connect to the T-58 transceiver units. The transceiver units are then joined together through a RF link that is set to simulate some desired condition. This link has several variations that will be considered below.

The simulated RF link has to have several different configurations for different testing situations. The simplest architecture is just to add attenuation on the link. The attenuation will be adjusted to simulate different link distances. The next more complex architecture is to have both attenuation and additive white noise. The next progression is to have an interfering source. An additional AN-50 that is sending out registration requests can be coupled into the RF link. Figure 3.2 is shown below and shows the different configurations of the simulated RF link.

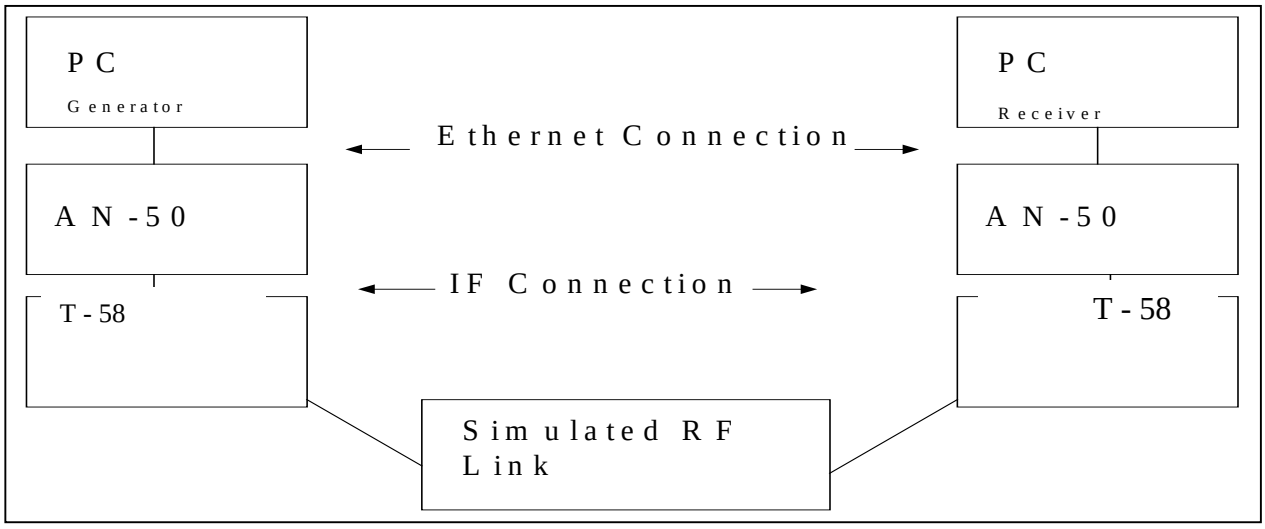

Fig. 3.1 General Test bed Architecture. The physical portion of the test bed, showing the terminals and the basic interconnects.

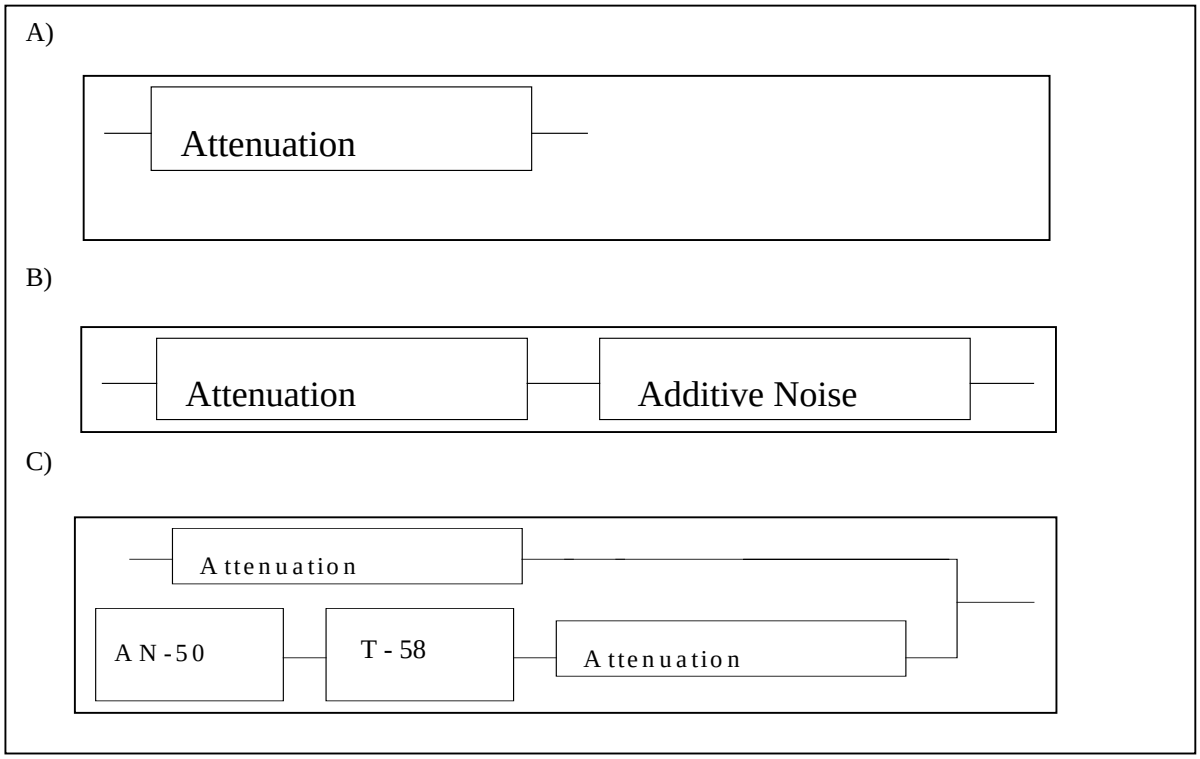

Fig. 3.2 RF link simulation environments. In (A) attenuation is used to simulate different antenna separation distances; in (B) white noise is added to the system; in (C) an additional terminal is used to act as an interfering source.

3.3 Hardware Selection: The signal attenuation block shown in the above section was implemented by using fixed value attenuators, as well as a step attenuator. The set of fixed attenuators were procured from the Electrical and Computer Engineering Department RF lab. The attenuators are fixed N-type attenuators from Weinschel Engineering. Not all of the attenuators were rated for use at this frequency (5.8GHz) so they had to be calibrated by using the network analyzer located in the Telecommunications lab in the ECE department. The fixed attenuators were labeled with the value of attenuation that was measured at the desired frequency of interest (5.8GHz). In addition a variable attenuator (HP 8494B) is also used with values between 0 and 11 dB in 1 dB steps. This device is rated for use up to 18GHz. The operation of the step attenuator was verified to be within 0.3 dB of the displayed value throughout its range, by using the network analyzer. This configuration provided attenuation between 106 and 56 db, corresponding to a maximum range of 113 miles under free space propagation conditions with 28dBi antennas, -86dbm receive sensitivity and 20dbm of transmit power.

The test bed allows for easy adjustment of the amount of additive noise induced into the system by using a wide band calibrated noise source that is on loan from The Spectrum Research Lab located at MSU. The noise source is a Noise Com NC6000 series broadband white noise source with a built in step attenuator.

For doing high frequency radio testing it is necessary to have very high quality cables with both low insertion loss and high isolation. The cables that were used for this project are manufactured by Easy Form Cable Corporation and are excellent for these criteria. They are a flexible cable, which is beneficial since several different configurations will need to be used. Rigid cables can meet the technical demands, but are more difficult to work with. Model EZ flex 402 cable was selected to meet all of the given requirements. A 2-way splitter and a 4-way splitter were procured from Mini-Circuits and are specified to work at 5.8 GHz.

The radio terminals and transceivers are manufactured by Redline Communications. The complete system is referred to as the AN-50 radio. The main components of the radio are the

AN-50 terminal and the T-58 transceiver. The radios, transceivers and some of the attenuators are shown in Fig. 3.3

Advanced Acoustic Concepts supplied the PCs that are used to generate and receive traffic. One terminal was a Compaq Evo N620c laptop with a Pentium M 1.6Ghz processor and 512 MB RAM and a gigabit Ethernet port. In early testing the other terminal was an IBM ThinkPad transnote. This machine did not have the resources to support the throughput we needed. It was subsequently discovered that this terminal was creating a bottleneck in the throughput. Final testing used a HP PC with a Pentium 4 2.8Ghz processor and 248 MB RAM and a 100 Mbps Ethernet adaptor.

3.4 Software Selection: To able to test the various different configurations and RF environments that we can create with the RF portion of the test bed we need tools that allow us to both generate traffic as we desire and be able to log the observed performance. MSU has procured and installed Omnicor's "IP Traffic Test & Measure" software suite. This software can generate up to sixteen simultaneous traffic streams. The parameters (e.g., packet size, priority, inter-packet delay time, packets per second, etc.) of each stream can easily be set by the GUI on a per connection basis. A screen shot of the parameters interface is shown below in Figure 3.4. The receiving computer measures round trip delay, lost packets, bit error rate and throughput. The software collects, stores, analyzes and graphs the data.

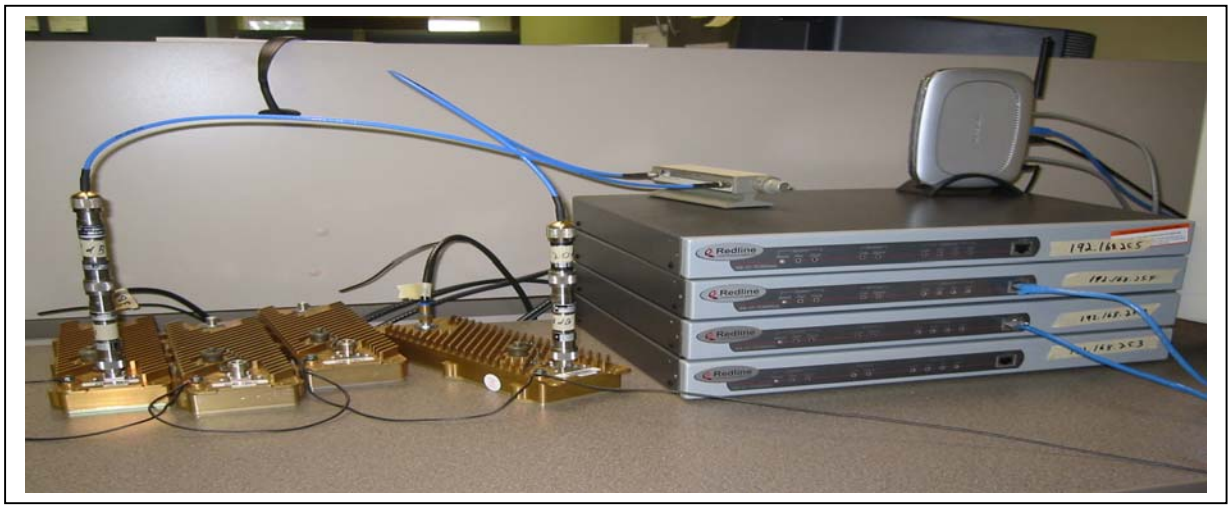

Fig 3.3 Redline AN-50s on the lab bench. 4 T-58 transceivers (left) and 4 AN-50 radio terminals (right) are shown on the lab bench. Fixed attenuators are connected directly to two of the terminals.

A Visual Basic (VB) script was written to do some analysis on several different data files at once as well. This allows for complete test set data to be calculated once and imported in one easy step.

The Omnicor software has been installed and tested on the Compaq laptop and the IBM Laptop. Figure 3.4 is a diagram of the IP Traffic measurement environment. As is evident in the figure there are many parameters that can be set for testing purposes. The number of packets can be set, as well as the payload of the packets. A random packet generator is built into the software. By setting the packet sized to a fix amount and then also setting the throughput the interpacket delay is automatically set to achieve the throughput with the packet size requested. This facility even works when pause and resume frames are being sent. Although IP Traffic has the ability to record the data as it is received, this function proved to provide a huge overhead that limited the throughput in the system, so it was not implemented during testing. If this function had not lowered the throughput so significantly the recorded data could be compared to the source data and bit error rate analysis could have been done.

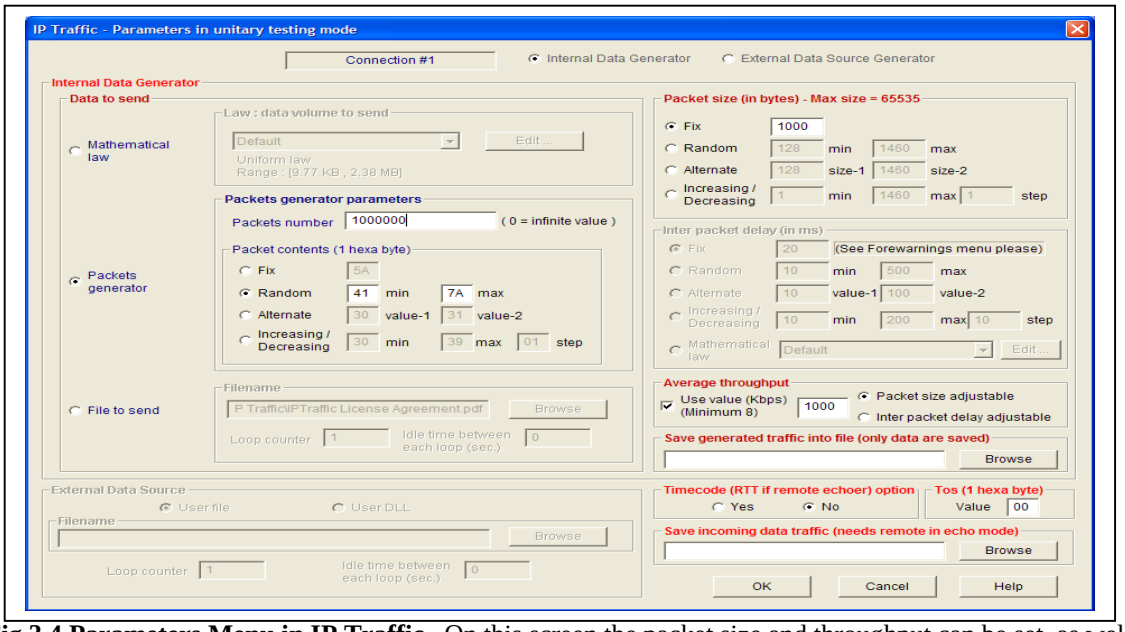

Fig 3.4 Parameters Menu in IP Traffic. On this screen the packet size and throughput can be set, as well as the type of data to be transmitted.

From the IP Generator – Parameters tab the protocol as well as the destination IP address and port can be specified. These values need to match with the values that are set under the IP Answering – Parameters + Statistics tab. The parameters #x button access the parameters screen shown in Figure 3.5.

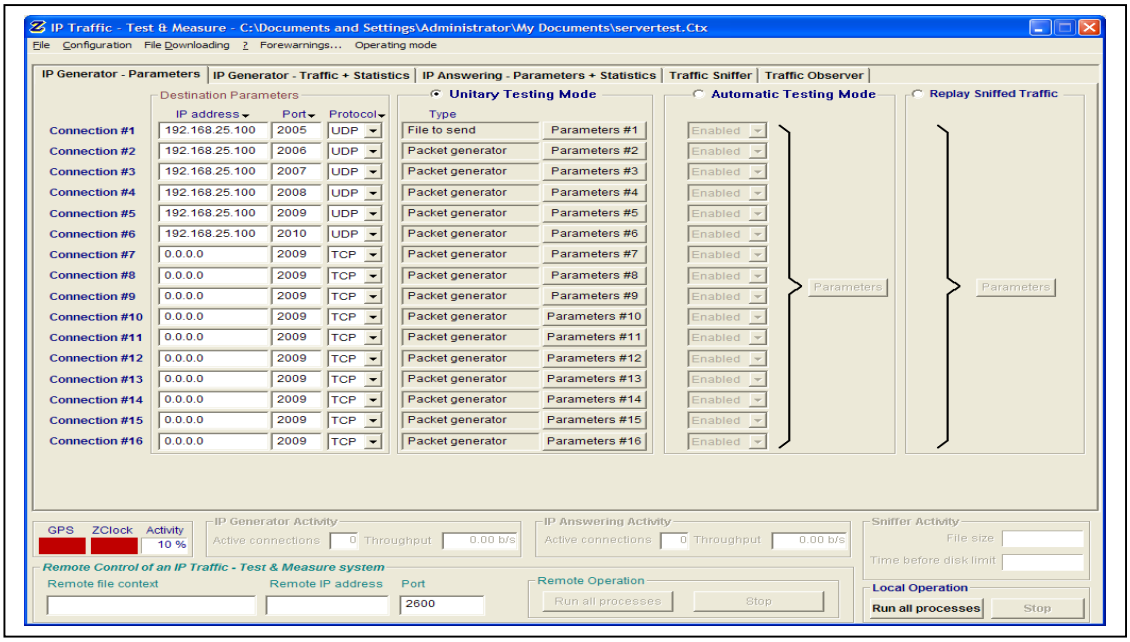
IP Traffic - Test & Measure - C:\Documents and Settings\Administrator\My Documents\servertest.Ctx
File Configuration File Downloading ? Forewarnings... Operating mode
IP Generator - Parameters
IP Generator - Traffic + Statistics
IP Answering - Parameters + Statistics
Traffic Sniffer
Traffic Observer
Destination Parameters
IP address
Port
Protocol
Unitary Testing Mode
Automatic Testing Mode
Replay Sniffed Traffic
Type
Connection #1 192.168.25.100 2005 UDP File to send Parameters #1
Connection #2 192.168.25.100 2006 UDP Packet generator Parameters #2
Connection #3 192.168.25.100 2007 UDP Packet generator Parameters #3
Connection #4 192.168.25.100 2008 UDP Packet generator Parameters #4
Connection #5 192.168.25.100 2009 UDP Packet generator Parameters #5
Connection #6 192.168.25.100 2010 UDP Packet generator Parameters #6
Connection #7 0.0.0.0 2009 TCP Packet generator Parameters #7
Connection #8 0.0.0.0 2009 TCP Packet generator Parameters #8
Connection #9 0.0.0.0 2009 TCP Packet generator Parameters #9
Connection #10 0.0.0.0 2009 TCP Packet generator Parameters #10
Connection #11 0.0.0.0 2009 TCP Packet generator Parameters #11
Connection #12 0.0.0.0 2009 TCP Packet generator Parameters #12
Connection #13 0.0.0.0 2009 TCP Packet generator Parameters #13
Connection #14 0.0.0.0 2009 TCP Packet generator Parameters #14
Connection #15 0.0.0.0 2009 TCP Packet generator Parameters #15
Connection #16 0.0.0.0 2009 TCP Packet generator Parameters #16
Enabled
Parameters
GPS
ZClock
Activity
10 %
IP Generator Activity
Active connections
Throughput
0.00 b/s
IP Answering Activity
Sniffer Activity
File size
Time before disk limit
Remote Control of an IP Traffic - Test & Measure system
Remote file context
Remote IP address
Port
2600
Remote Operation
Run all processes
Stop
Local Operation
Run all processes
Stop

Fig 3.5 IP Generator Parameter Tab. This tab sets the protocol to use as well as the destination IP address and port.

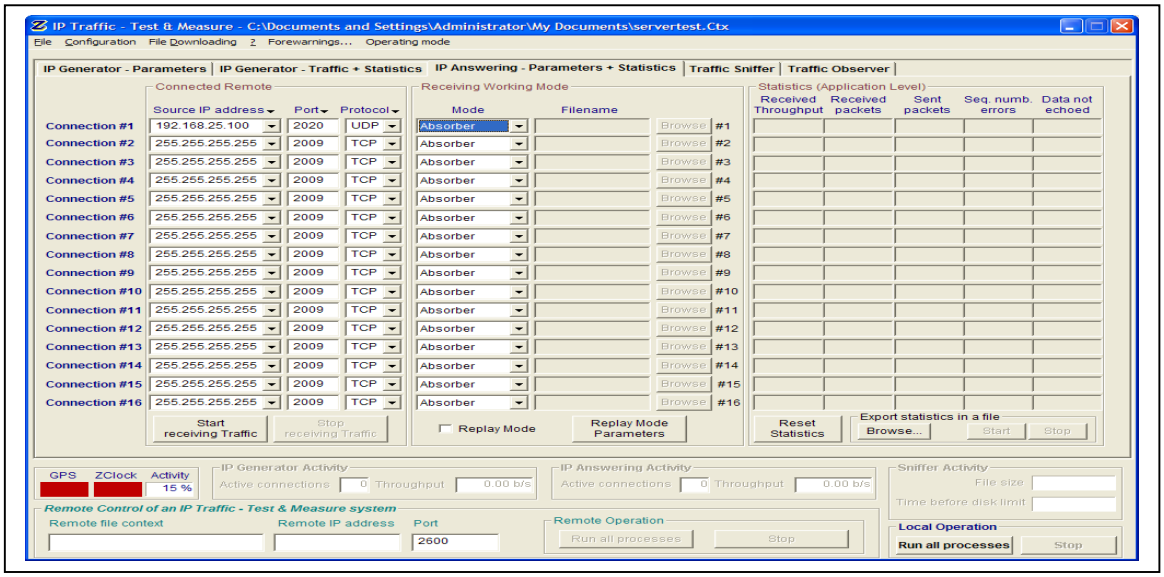

Fig 3.6 IP Answering Parameters Tab. This tab sets the source IP address and port. The protocol is also specified on this tab.

An important part of the test bed is the web interface for the AN-50. The system status screen is shown below in Figure 3.7. This screen shows the current received power (RSSI), signal to noise and distortion ratio (SINADR), as well as statistics on packet retransmissions on the wireless link. Redline has released RF Monitor, a tool that automatically polls this web interface and plots the results. This software gives much more consistent results then what was achievable by manually observing the web interface, which updated more slowly. The RF Monitor software was installed on the PCs. A typical graph produced by RF Monitor is shown in Figure 3.8

For collecting end-to-end performance data "IP Traffic Test and Measure" will be used to record the data regarding throughput and delay. This software will also run the packet generation so that the data flow can be shaped to emulate data from acoustical sensors, the primary data source that AAC plans to use. The Parameters tab is shown in Fig. 3.4. This tab adjusts the number of packets, packet size and packet rate. The payload of the packet can be set by several parameters as well. Random data is used to emulate traffic from a sensor.

Iperf, an open source command line network analysis tool has been installed on several computers and will be used to validate the results of the IP Traffic testing. Iperf runs for a set amount of time and has the ability to generate packets of various sizes under both UDP and TCP protocol. The results from Iperf are given as average throughput over a given time interval, one second was used in this case. The total average throughput for the duration of the test is also reported as well as jitter and packet loss statistics. Readout of typical Iperf results is shown below in Figuer 3.9. Iperf is freely available. This software was able to produce much higher throughputs then what IP Traffic did. The results obtained with Iperf are more inline with the manufacturers specifications for the radio system.

An actual deployment test bed is also necessary to support the lab findings and provide a final proof of performance. This test can be done using the existing Redline equipment. This test is a simple throughput test under a deployment scenario of 20 miles range using two of the 12° sector antennas. The antenna alignment is done by listening to the audible sweep that is transmitted from the transceiver unit while adjusting the antenna aiming. The higher the frequency of the

sweep, the higher the received power level is. It was observed that small aiming differences did not result in a significant change in signal quality since the beam pattern of the antennas is reasonable flat near zero degrees.

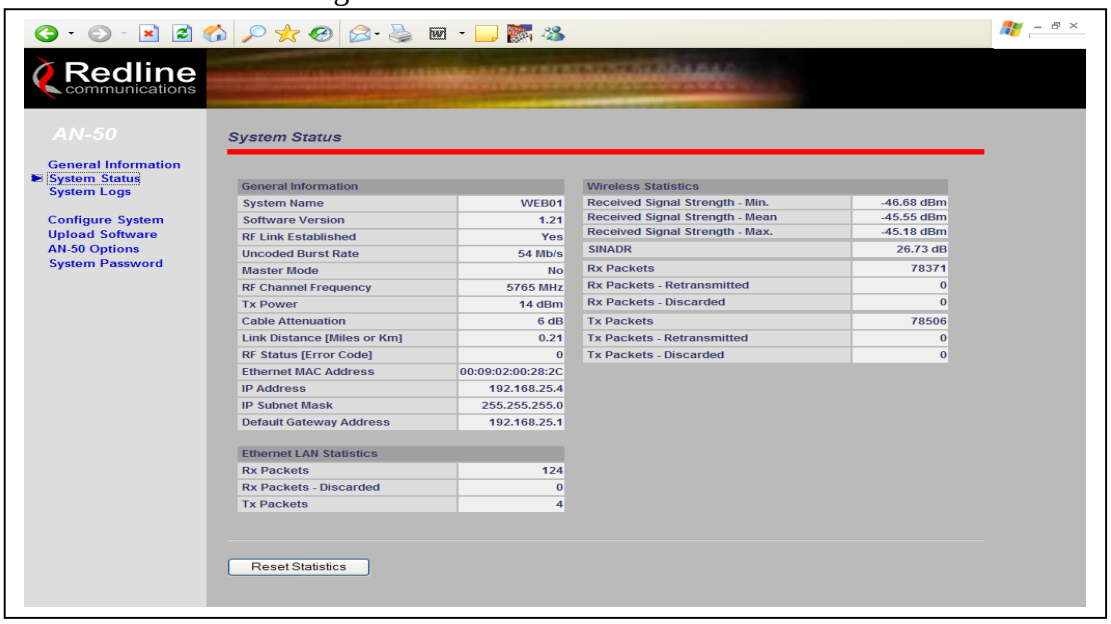

Fig. 3.7 System Status Page. The system status page of the Redline web interface displays information such as Received Signal Strength (RSSI), Signal to Noise and Distortion Ratio (SINADR), and packet retransmission data.

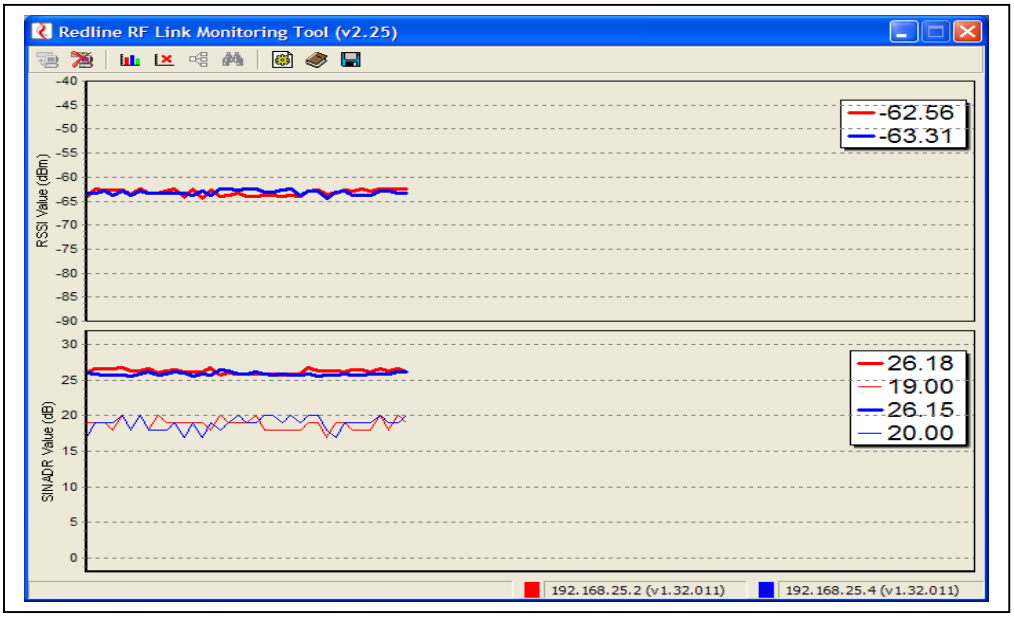

Fig. 3.8 A typical output graph from RF Monitor. This data, along with the measured throughput can be used to plot throughput vs. SINADR. The lighter line on the SINADR plot is the transmit power.

```
------------------------------------------------------------
Server listening on UDP port 5001
Receiving 1470 byte datagrams
UDP buffer size:  128 MByte
------------------------------------------------------------


[1932] local 192.168.25.100 port 5001 connected with 192.168.25.200 port 1039
[ ID] Interval       Transfer     Bandwidth       Jitter   Lost/Total Datagrams
[1932]  0.0- 1.0 sec  5.04 MBytes  42.3 Mbits/sec  0.126 ms -842149805/ 4244 (-2
e+007%)
[1932]  0.0- 1.0 sec  842150451 datagrams received out-of-order
[1932]  1.0- 2.0 sec  5.09 MBytes  42.7 Mbits/sec  0.113 ms  677/ 4311 (16%)
[1932]  2.0- 3.0 sec  5.10 MBytes  42.8 Mbits/sec  0.102 ms  672/ 4310 (16%)
[1932]  3.0- 4.0 sec  5.10 MBytes  42.8 Mbits/sec  0.089 ms  675/ 4312 (16%)
[1932]  4.0- 5.0 sec  5.09 MBytes  42.7 Mbits/sec  0.088 ms  676/ 4309 (16%)
[1932]  5.0- 6.0 sec  5.10 MBytes  42.8 Mbits/sec  0.082 ms  675/ 4312 (16%)
[1932]  6.0- 7.0 sec  5.05 MBytes  42.3 Mbits/sec  0.151 ms  672/ 4273 (16%)
[1932]  7.0- 8.0 sec  5.10 MBytes  42.8 Mbits/sec  0.132 ms  675/ 4313 (16%)
[1932]  8.0- 9.0 sec  5.10 MBytes  42.8 Mbits/sec  0.117 ms  671/ 4309 (16%)
[1932]  9.0-10.0 sec  5.10 MBytes  42.8 Mbits/sec  0.102 ms  674/ 4312 (16%)
[1932]  0.0-10.0 sec  51.0 MBytes  42.7 Mbits/sec  1.796 ms 6713/43057 (16%)
```

Fig. 3.9 A typical readout after running Iperf for duration of 10 seconds. In this test the UDP source was set to 50Mbps. Since the link could only sustain 42.7Mbps 16% of the datagrams were lost.

4. Test Procedure

An extensive test plan had been developed to do complete testing on the Redline equipment and evaluate its suitability to meet the needs of AAC. A copy of the test plan can be found in appendix 5. The test plan was completed with the exception of doing point to multipoint mode testing due to a hardware failure in the base station terminal. The interference testing had to be modified as well.

The first test was designed to determine the effects of packet size on throughput. The test bed was configured using architecture A shown in Figure 3.2. The size of the UDP packets were varied by setting the packet size parameter on the IP-Traffic generator screen to the desired value. The interpacket delay was then automatically controlled by IP Traffic to keep a throughput value of 50Mbps, as was specified in the throughput field. The use of flow control limited the throughput to whatever the capacity of the radio link was for that size of packet. This throughput value is what was recorded in the raw data logs taken by IP Traffic. The traffic

generation was set to produce random packet contents for a duration of 1,000,000 packets. The average result over the test interval was extracted by using a VB script. The script can be found in Appendix 1. The traffic generation and data logging functions are not integrated in IP Traffic, so the data logging had to be started manually before the traffic generation, and then stopped after the traffic generation section had completed. The script finds the first instance of throughput and averages the data until the link is silent again. Test results are discussed in Section 5.

Subsequent testing was done to determine the effect of RSSI on throughput. To do this the packet size was fixed at 1300 bytes and the amount of attenuation on the link was varied throughout the operating range of the transceiver. This packet size is close to the size of packets sent by AAC sensors. The sensitivity of the receiver is –86 dbm, and the dynamic range is specified as >50db. So the attenuation when connected to 20dbm source had to range from below 56db to 106db to cover the entire operating range. Throughput was extracted from the raw data files collected by IP Traffic using the VB script, as stated above. The RSSI data was manually observed from the web interface, in the initial testing. Later testing using the Iperf software also included the use of RF Monitor, which graphed the values of RSSI and SNR. The Iperf software provided the average result over the test interval so no additional analysis was needed on that data. More information on Iperf can be found in Appendix 2 and the test results in Section 5.

The next testing was to determine the effect of additive noise on the throughput of the system. This test used architecture B, shown in figure 3.2. To do this a signal level was set by adding in a fixed amount of attenuation, then adjusting the attenuator on the noise source set the noise level. The SNR was adjusted over a range so that the throughput varied from optimum (no additive noise) to total link loss. The traffic generation and data logging was only done with IP Traffic for this test, due to the availability of the noise source. The average throughput was extracted from the raw data files using the VB script, as before. Results are given in Section 5.

For the field testing the radio was run on different channels and with different software configurations to see if they had any effect on end user throughput. A link was set up between

Cobleigh Hall, on the MSU campus and a remote site located twenty miles north on Rocky Mountain Road. The Cobleigh Hall antenna was located on the roof, approximately 80 feet above ground level. The antenna at the Rock Mountain Road site was mounted on an 8-foot mast. The path between the locations was line of site with no blockage within the Fresnel zone. Figure 4.1 shows a terrain map of the area with the two antenna locations labeled. The elevation difference between the sites in combination of the antenna heights provided for Fresnal zone clearance as shown in Figure 4.2. A photo of the remote station is shown below in Figure 4.3. The view from the Cobleigh Hall site towards the remote site is shown in Figure 4.4. For these tests 28 dBi sector antennas with a beam width of 4.5 degrees were used at each end. A portable generator powered the remote site. Results are shown in Section 5.

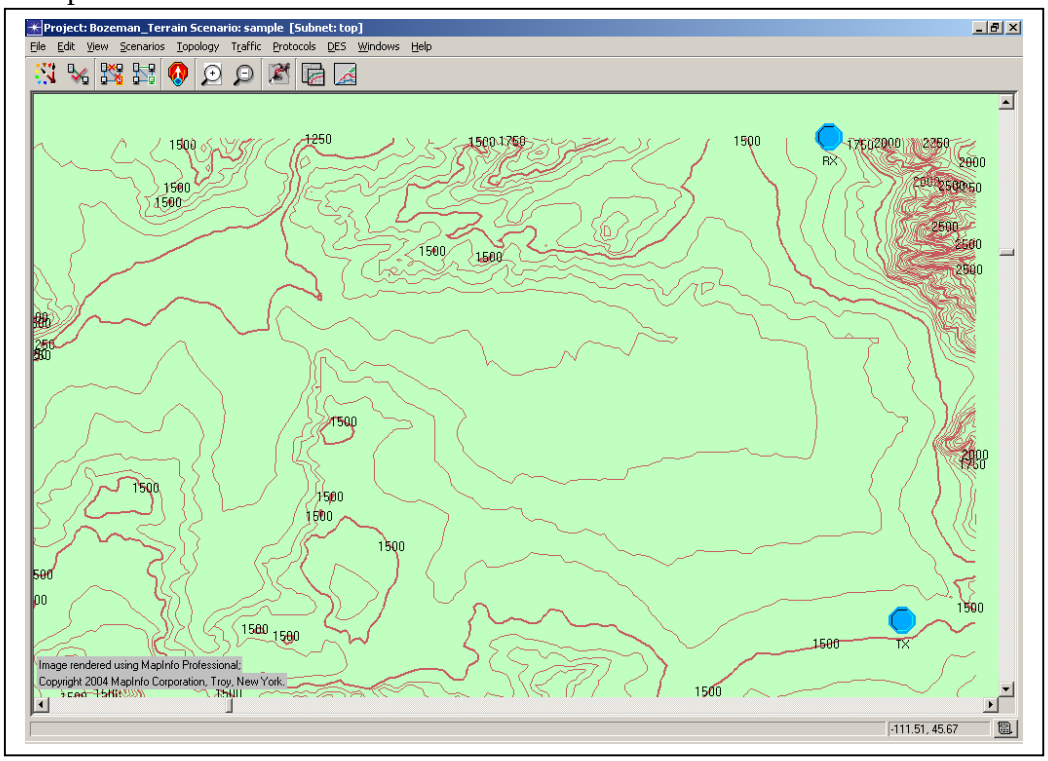
Project: Bozeman_Terrain Scenario: sample [Subnet: top]
File Edit View Scenarios Topology Traffic Protocols DES Windows Help
RX
TX
Image rendered using MapInfo Professional
Copyright 2004 MapInfo Corporation, Troy, New York.
-111.51, 45.67

Fig. 4.1 Locations of the transmit and receive sites

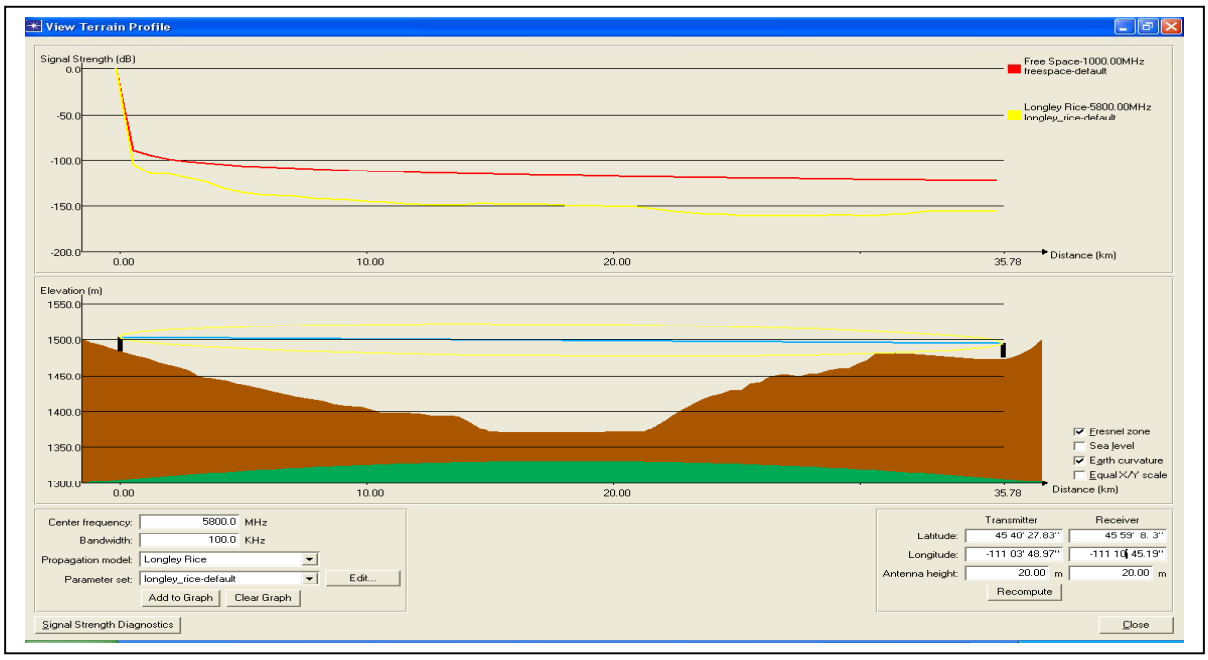

Fig. 4.2 Fresnal Zone Clearance

Fig. 4.3 The Remote Site for the Long Range Test. In this photo the generator is visible in front of the SUV, as well as the antenna and mast at the rear of the vehicle. The laptop and radio were set up on a table at the rear of the vehicle.

Fig. 4.4 View From the Cobleigh Hall Site Towards the Remote Site.

5. Test Results

A series of tests have been done on the Redline AN-50 system to evaluate its performance. Bench tests covering the effects of packet size, received signal strength, SNR and various user-defined parameters within the radio were conducted. A long-range test was also conducted by using two sector antennas to establish a link at a range of about 20 miles. In the field test several data runs were taken to ensure reliability since the test cannot easily be redone. The only things that could be varied under these conditions were the user definable parameters inside for the firmware and the radio channel.

Lab Tests

5.1 Packet Size Effects: The explicit effect of variation of the packet size was investigated using the IP Traffic test and measure suite. Packet size was varied over a large range to see what affect that had on user throughput. Below in Figure 5.1 is a graph of the data, showing minimal differences due to packet size. What is most important to note is the trend on the graph of increasing throughput as the packet size is increased, up to a point at which the graph flattens out. This is due to the overhead of each packet is set by the constant length header, so the

overhead becomes less important as the payload size increases. The packet size was increased to a maximum of 1480 bytes, the size of the Ethernet frame payload. Packets that are larger than this are dropped by the AN-50. In order to use larger packets, such as MPLS packets, on a network with the AN-50 they need to be fragmented before being sent to the AN-50.

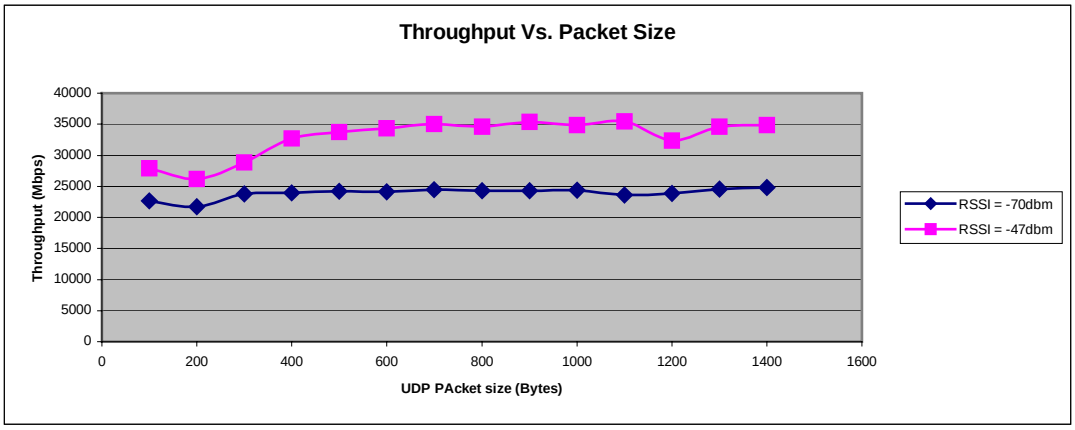

Fig. 5.1 Throughput Vs. Packet Size. The effects of packet size are minimal once the payload size dominates the total packet size.

5.2 Received Signal Level Effects: Several tests were run where the received power level was varied and the throughput was measured. These tests were taken with both IP traffic and Iperf as

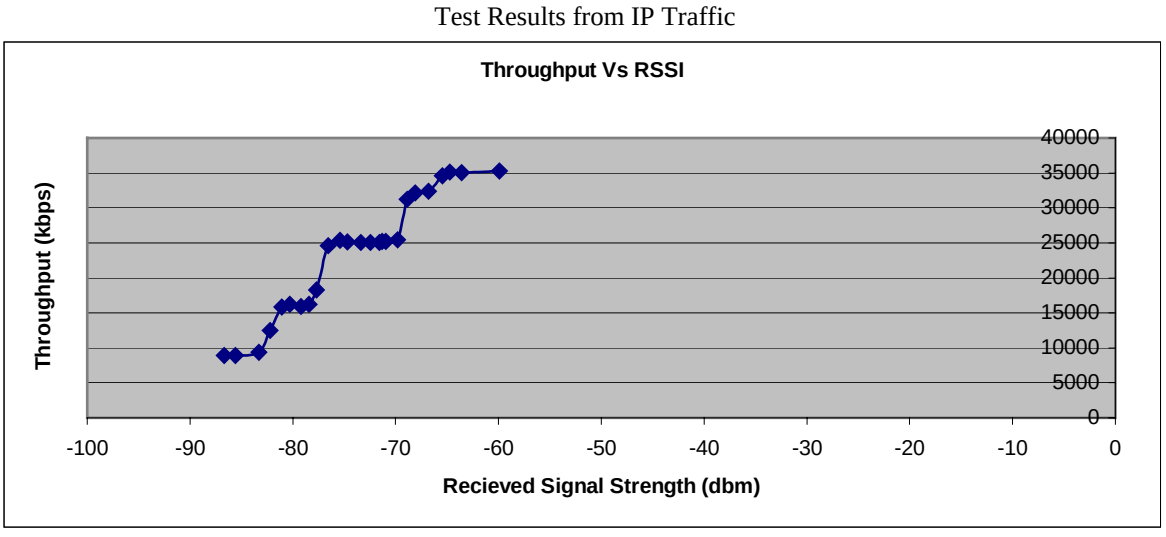

Figure 5.2 The throughput results from IP Traffic. Notice how clearly changes in modulation format are shown as stairs in the graph.

the testing software. This is where it first becomes apparent that Iperf is better suited to run tests at high speeds. As the signal level is lowered it gets closer to the thermal noise floor. This in effect decreases the SNR without the use of a noise source. The results are shown in Figure 5.2.

The same tests were run using Iperf as the software to both generate and measure the traffic levels. The results shown in Figure 5.3 show a similar trend. Most noticeably the throughput is consistently higher when there is a large amount of received power. The steps show a similar structure for the first three level reductions. The wide fluctuations that are seen as the signal level gets very low is probably due to a shorter testing time with Iperf then with IP traffic. The modulation was probably adapting during the duration of these tests and it didn't run for a long enough time to average that out.

In both sets of tests the throughput minimum is observed at about –86 dBm, corresponding to the manufacturer's specification for received signal sensitivity.

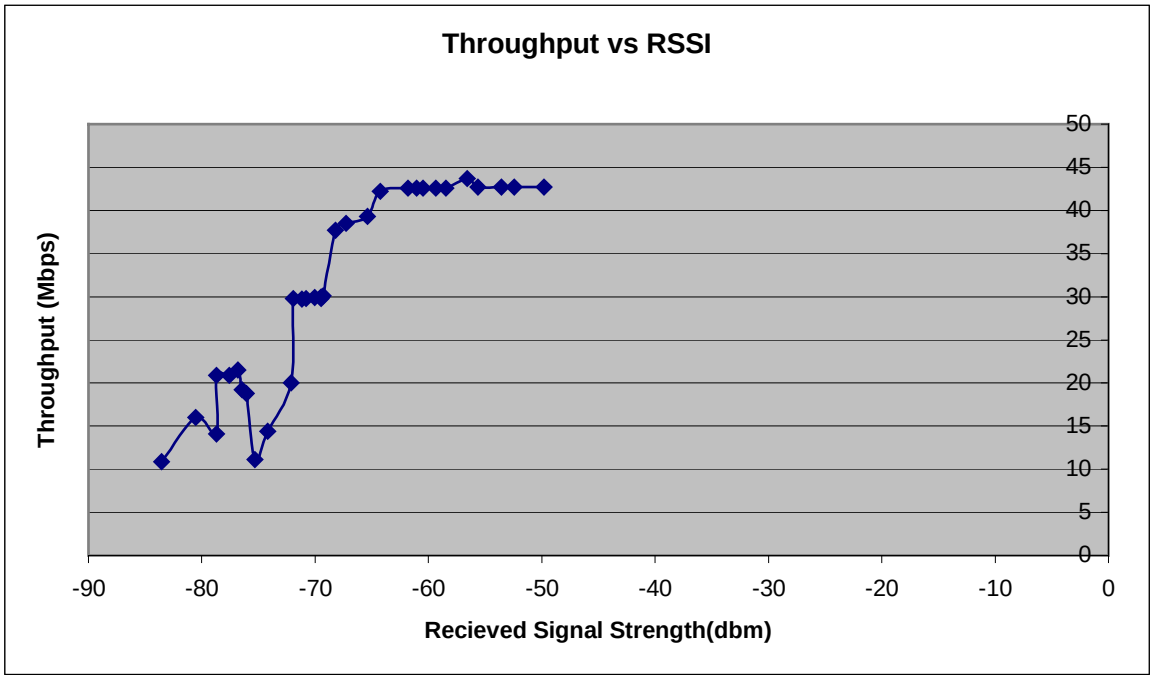

Fig. 5.3 Throughput Vs. RSSI data from IPERF.

5.3 Additive Noise Effects: The effect of injecting various amounts of noise into the signal was investigated. This was done at several different levels of signal attenuation. For a fixed level of signal attenuation the noise power was adjusted by varying the level of attenuation on the front of the noise source. The results are shown in Figure 5.4. This only changes the amount of noise added to the signal, and not the power level of the information signal itself.

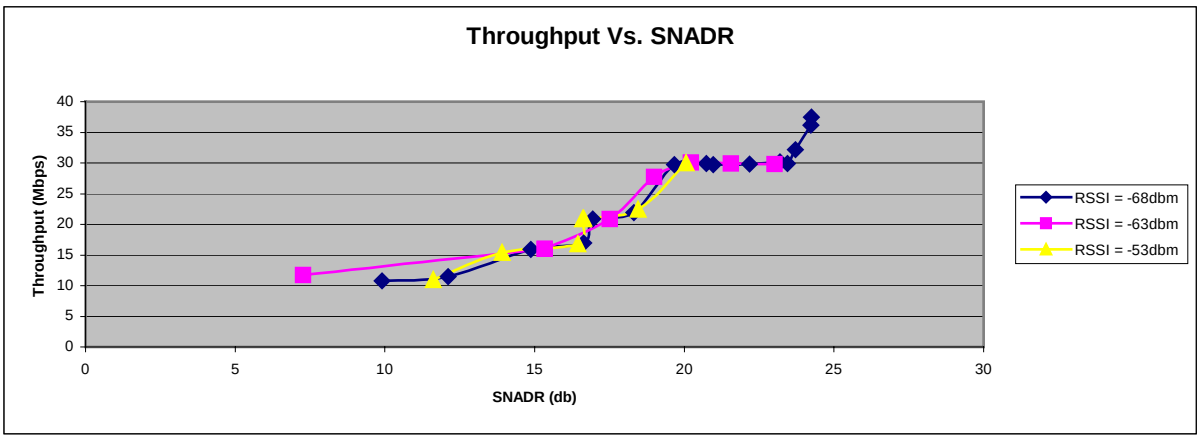

Fig 5.4 Throughput Vs. SNADR based on IP Traffic Data. Notice that the three graphs for different levels of received power all overlay each other. This shows that the SNR is the determining factor in what level of throughput is possible

5.4 Interference Effects: The effect of interference from another radio source on a different channel was investigated by having a third AN-50 terminal connected to the RF link. This terminal constantly is trying to set-up a link with another radio. The radio performed very well in the presence of interference. Figure 5.5 shows that the throughput only dropped down to 33 Mbps as measured by Iperf in the presence of very strong interference. Note that the RSSI was only –64dbm as reported by the AN-50 web interface. The interference is much stronger for this test than was the desired signal. This shows that the filters in the AN-50 do an excellent job of rejecting out of band interference.

The case of an interferer being in an adjacent and partially overlapping channel was investigated as well. The results of this test are shown in Figure 5.6. This test shows that even when the interference occupies some of the channel bandwidth the link is still able to be persistent. This is

probably due to the use of OFDM, which allows for sub-channels to be utilized, some of which are not sharing any bandwidth with the interferers.

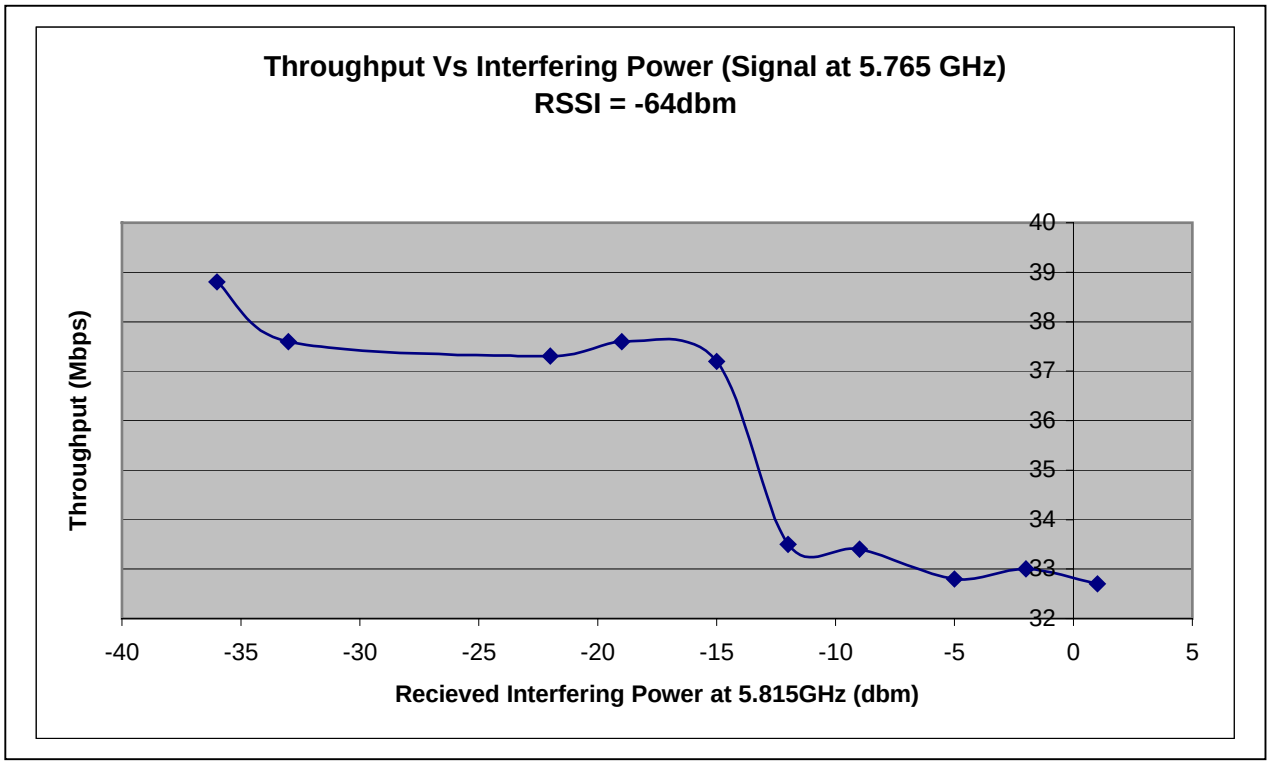

Fig 5.5 Throughput Vs Received Out of Band Interference. The throughput is shown here for various amounts of out of band interference being caused by a third AN-50 terminal.

The last case is when the interferer is occupying the same bandwidth as the desired signal. In this case filters or sub-channelization is not efficient since there is interference in the entire signal bandwidth. Figure 5.7 shows that the throughput is severely inhibited by the presence of co-channel interference. This interference is best mitigated through channel selection and the use of more directive antennas that don't couple in extraneous energy from a wide angle.

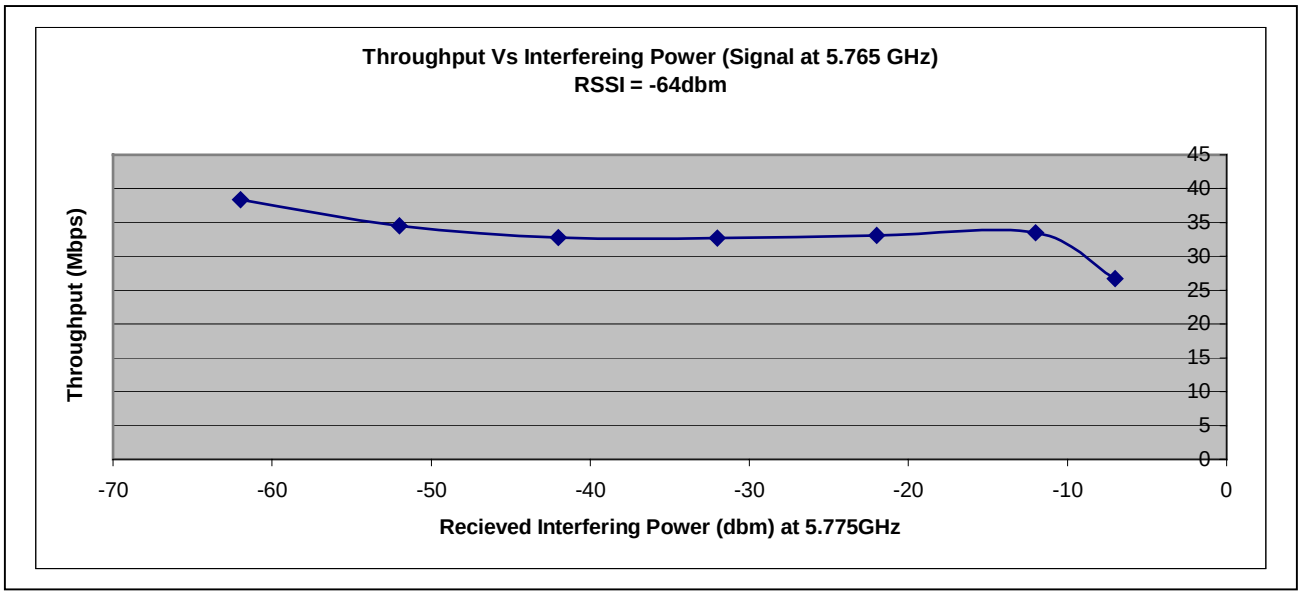

Fig. 5.6 The Effect of Interference In an Overlapping Channel. In this series of tests the occupied bandwidth of the signal is from 5.765GHz to 5.785GHz. The signal bandwidth is from 5.755GHz to 5.775GHz.

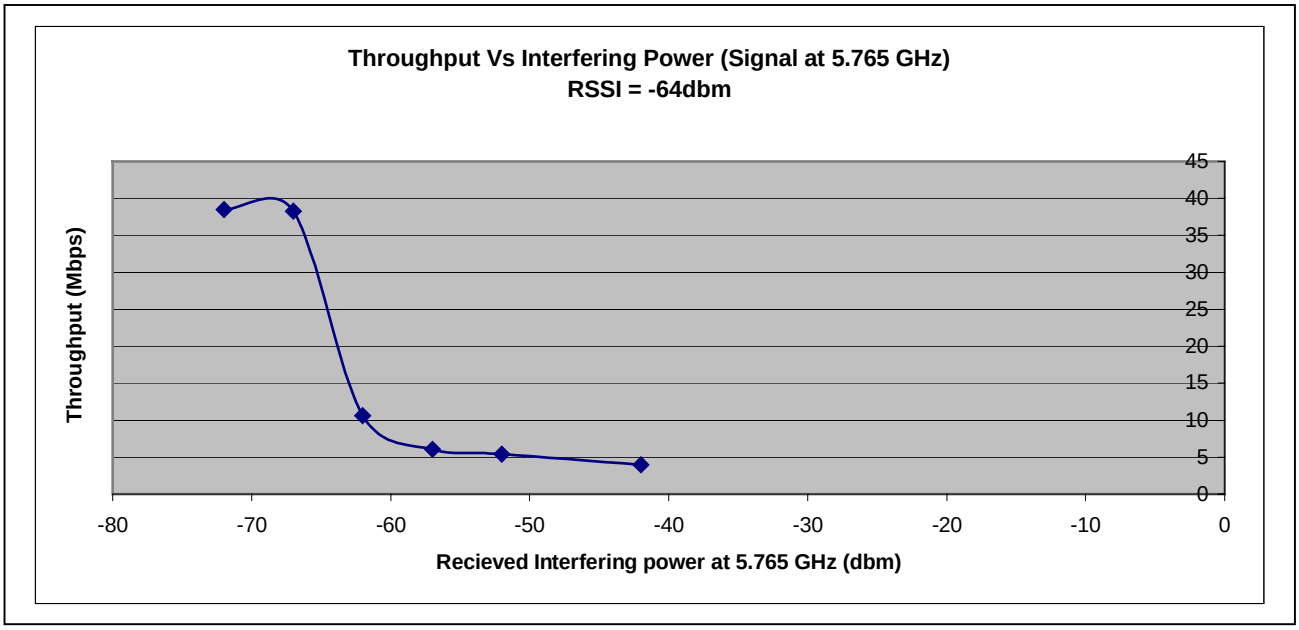

Fig. 5.7 The Effect of Co-channel Interference on Throughput Between Two AN-50 Radios.

Long Range Field Test

5.5 Long Rage Tests: A set of long range field tests were conducted to verify the bench testing that had been done to that point. The throughput measured on this test was less than what was expected from the initial bench testing. This is most likely due to the channel experiencing reflections and dispersion in the time domain. This effect was not simulated in the lab

environment. The alignment of the antennas was done by first using a visual alignment and then fine-tuning by using the built in buzzer in the transceivers. Aiming proved not to be critical, as the small changes in angle did not change the received power level much since the beam pattern is relatively flat. The range as given by the user interface of the Redline terminal was 17.03 miles.

The severe difference in throughput in different channels shown in Figure 5.8 may have been due to the presence of interfering signals. The signal propagation should not differ significantly between the different channels. The possibility that additional noise, such as local microwave radiation from other users of the same spectrum, which might be contributing to the lower SNR was explored. An RF spectrum analyzer was hooked to the antenna at the Cobleigh Hall site to look for sources of interference, and to measure the noise floor. The noise floor was observed o be at about –100 dBm. There were two narrow band interferes noted to be present. Their characteristics are shown below in Figure 5.9. There is a possibility that there was an interferer present at the remote site that could not be seen at the Cobleigh Hall site. This would impair the link, yet not be detectable from the Cobleigh Hall site.

Frequency, MHz	Power level, dBm	Channel
5764.6	~-90	2A
5821.8	~-91	5

Fig. 5.8 The two interferers present at the Cobleigh Hall site.

Channel	Throughput (Mbps)
2A	20.06
3	19.87
4	13.09
4A	13.14
5	11.05

Fig 5.9 The effect of utilizing different channels

The effect of using Redline's proprietary encryption was investigated as well. The results show little difference if it is on or off. For all of these results the modulation format was set to be adaptive with a maximum bit rate of 54Mbps with a step size of two levels. This proved to give better results than any of the attempts to have a fixed level of modulation.

Encryption	Throughput (Mbps)
On	19.48
Off	19.94

Fig 5.10 The Effect of Encryption on Throughput.

6. Conclusions

The Redline communications equipment and the 802.16 standard that they are based have been demonstrated to be able to provide a reliable telemetry link. Although the specified throughput of 48Mbps at the Ethernet port was not attainable the system sill performed well. The highest throughput measured was 44 Mbps at the Ethernet under ideal conditions. The radio performed well in the presence of adjacent channel interference, likely due to the use of the adaptive modulation, error correction and the use of OFDM. The long-range test showed that the system, when properly configured, quickly and easily establishes a link that performs well. With the first attempt at antenna alignment done purely by visual reference the link became operational as soon as both units were powered on.

The range of an 802.16 radio can be extended by the use of advanced receiver and transmitter antenna design and signal processing. Future work on this project involves integrating an adaptive antenna with an IEEE 802.16 radio transceiver. The antenna will provide for higher on axis gain, as well as being more directional so that interference from off axis sources will be minimized. This will aid in both system security and throughput.

Glossary

AN-50	Redline Communications' Access Node-50 Broadband Fixed Wireless (BFW) system.
Antenna	A device for transmitting and/or receiving a radio frequency (RF). Antennas vary in design and frequencies supported.
Antenna Gain	The measure of antenna performance relative to a theoretical antenna called an isotropic antenna.
ARQ	Automatic Repeat Request. This is the protocol used over the air for error correction.
Beamwidth	The angle of signal coverage provided by an antenna.
BFW	Broadband Fixed Wireless
Bps (Bits Per Second)	A unit of measurement for the rate at which data is transmitted.
BPSK	Binary Phase Shift Keying.
Channel	A communications path wide enough to permit a single RF transmission.
dB	A ratio expressed in decibels.
dBi	A ratio, measured in decibels, of the effective gain of an antenna compared to an isotropic antenna.
dBm	Decibels above a milliwatt
DHCP	Dynamic Host Configuration Protocol. A DHCP server will automatically issue IP addresses within a specified range to devices on a network.
Directional Antenna	An antenna that concentrates transmission power into one direction.
Encryption	For the purposes of privacy, the transformation of data into an unreadable format until reformatted with a decryption key.
Ethernet	A LAN architecture using a bus or star topology
FD	Full Duplex. Refers to the transmission of data in two directions simultaneously (i.e. a telephone)
FWA	Fixed Wireless Access
Gain	The ratio of the output amplitude of a signal to the input amplitude of a signal. Typically expressed in decibels (dB).
Gateway	A network point that acts as an entrance to another network.
GHz	Gigahertz. 1,000,000,000 Hz, or 1,000 MHz
GUI	Graphical User Interface
Hertz (Hz)	The international unit for measuring frequency, equivalent to the number of cycles per second. One megahertz (MHz) is one million Hertz. One gigahertz (GHz) is one billion Hertz.
IF	Intermediate Frequency.
IP (Internet Protocol)	See TCP/IP.
Isotropic	A theoretic construct of an antenna that radiates its signal 360 degrees both vertically and horizontally—a perfect sphere. Generally used as a reference.
IXC (Inter-exchange Carrier)	A long-distance phone company.
LAN (Local Area Network)	A data communications network, typically within a building or campus linking computers, printers and other devices together.
LEC (Local Exchange Carriers)	The traditional local wired phone company.
LED	Light Emitting Diode
LOS	Line Of Sight. A clear direct path between two antennas, with

	no obstructions within the first Fresnel zone.
MAC (Media Access Control)	A unique number assigned to a network device. It corresponds to the ISO Network Model Layer 2 data link layer.
MHz	Megahertz. 1,000,000 Hz
Modem (Modulator / DEModulator)	A hardware device that converts digital data into analog and vice versa.
Modulation	Any of several techniques for combining user information with a transmitter carrier signal.
Multipath	The radio echoes created as a radio signal bounces off of objects.
NLOS	Non Line Of Sight. Completely obstructed path between two antennas.
OFDM	Orthogonal Frequency Division Multiplexing. OFDM spreads data to be transmitted over a large number of orthogonal carriers.
OLOS	Optical Line Of Sight. A clear direct path between two antennas, with obstructions within the first Fresnel zone.
Packet	A bundle of data organized in a specific way for transmission. The three principal elements of a packet include the header, the text, and the trailer (error detection and correction bits).
PHY (Physical Layer)	Provides for the transmission of data through a communications channel by defining the electrical, mechanical, and procedural specifications.
PTP	Point to Point
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
Receiver Sensitivity	A measurement of the weakest signal a receiver can receive and still correctly translate it into data.
RF	Radio Frequency
Rx	Receiver
S/N	Signal to Noise Ratio
SINADR	Signal to noise and distortion ratio.
TCP/IP (Transmission Control Protocol/Internet Protocol)	The standard set of protocols used by the Internet for transferring information between computers, handsets, and other devices.
TFTP	Trivial File Transfer Protocol
Tx	Transmitter

Appendix 1

This macro takes the raw IP Traffic data files that are saved as text files and stored in the C:\SampleData file.

```
Sub Macro2()
    Dim objFSO As New FileSystemObject
    Dim DataDir As Folder
    Dim DataDirFiles As Files
    Dim DataFile As File
    Dim stream As TextStream

    Set DataDir = objFSO.GetFolder("C:\SampleData")
    j = 2

    For Each DataFile In DataDir.Files

        Set stream = DataFile.OpenAsTextStream

        stream.ReadLine
        stream.ReadLine
        stream.ReadLine
        stream.ReadLine

        I = 1

        RunningTotal = 0
        Start = 0
        Ender = 0

        While Not stream.AtEndOfStream

            temp = stream.ReadLine
          ' ActiveSheet.Cells(j, 10) = temp
            temp2 = Split(temp, " ")

            temp3 = Split(temp2(3), "s")

            If IsNumeric(temp3(1)) Then
```

```
            Data = CDbl(temp3(1))
         Else
            Data = 0
         End If

         If Data = 0 And Ender = 0 Then
            Start = I
         Else
            If Data > 0 Then
               RunningTotal = Data + RunningTotal
               Ender = I
            End If
         End If

         I = I + 1

      Wend
      Average = RunningTotal / (Ender - Start)

      ActiveSheet.Cells(j, 1) = DataFile.Name
      ActiveSheet.Cells(j, 2) = Average
      ActiveSheet.Cells(j, 3) = Start
      ActiveSheet.Cells(j, 4) = Ender
      ActiveSheet.Cells(j, 5) = RunningTotal

      j = j + 1
   Next


End Sub
```

Appendix 2

Iperf commands and options

Command line option	Environment variable option	Description
Client and Server options		

`-f, --format` *`[bkmaBKMA]`*	`$IPERF_FORMAT`	A letter specifying the format to print bandwidth numbers in. Supported formats are
		`'b' = bits/sec  'B' = Bytes/sec`
		`'k' = Kbits/sec  'K' = KBytes/sec`
		`'m' = Mbits/sec  'M' = MBytes/sec`
		`'g' = Gbits/sec  'G' = GBytes/sec`
		`'a' = adaptive bits/sec  'A' = adaptive Bytes/sec`
		
		The adaptive formats choose between kilo- and mega- as appropriate. Fields other than bandwidth always print bytes, but otherwise follow the requested format. Default is 'a'.
		NOTE: here Kilo = 1024, Mega = 1024^2 and Giga = 1024^3 when dealing with bytes. Commonly in networking, Kilo = 1000, Mega = 1000^2, and Giga = 1000^3 so we use this when dealing with bits. If this really bothers you, use -f b and do the math.

`-i, --interval` *`#`*	`$IPERF_INTERVAL`	Sets the interval time in seconds between periodic bandwidth, jitter, and loss reports. If non-zero, a report is made every *interval* seconds of the bandwidth since the last report. If zero, no periodic reports are printed. Default is zero.
`-l, --len` *`#[KM]`*	`$IPERF_LEN`	The length of buffers to read or write. Iperf works by writing an array of *len* bytes a number of times. Default is 8 KB for TCP, 1470 bytes for UDP. Note for UDP, this is the datagram size and needs to be lowered when using IPv6 addressing to 1450 or less to avoid fragmentation. See also the -n and -t options.
`-m, --print_mss`	`$IPERF_PRINT_MSS`	Print the reported TCP MSS size (via the TCP_MAXSEG option) and the observed read sizes which often correlate with the MSS. The MSS is usually the MTU - 40 bytes for the TCP/IP header. Often a slightly smaller MSS is reported because of extra header space from IP options. The interface type corresponding to the MTU is also printed (ethernet, FDDI, etc.). This option is not implemented on many OSes, but the read sizes may still indicate the MSS.
`-p, --port` *`#`*	`$IPERF_PORT`	The server port for the server to listen on and the client to connect to. This should be the same in both client and server

		Default is 5001, the same as ttcp.
`-u, --udp`	`$IPERF_UDP`	Use UDP rather than TCP. See also the -b option.
`-w, --window` *#[KM]*	`$TCP_WINDOW_SIZE`	Sets the socket buffer sizes to the specified value. For TCP, this sets the TCP window size. For UDP it is just the buffer which datagrams are received in, and so limits the largest receivable datagram size.
`-B, --bind` *host*	`$IPERF_BIND`	Bind to *host*, one of this machine's addresses. For the client this sets the outbound interface. For a server this sets the incoming interface. This is only useful on multihomed hosts, which have multiple network interfaces. For Iperf in UDP server mode, this is also used to bind and join to a multicast group. Use addresses in the range 224.0.0.0 to 239.255.255.255 for multicast. See also the -T option.
`-C, --compatibility`	`$IPERF_COMPAT`	Compatibility mode allows for use with older version of iperf. This mode is not required for interoperability but it is highly recommended. In some cases when using representative streaming you could cause a 1.7 server to crash or cause undesired connection attempts.
`-M, --mss` *#[KM}*	`$IPERF_MSS`	Attempt to set the TCP maximum segment size (MSS) via the TCP_MAXSEG option. The MSS is usually the MTU - 40 bytes for the TCP/IP header. For ethernet, the MSS is 1460 bytes (1500 byte MTU). This option is not implemented on many OSes.
`-N, --nodelay`	`$IPERF_NODELAY`	Set the TCP no delay option, disabling Nagle's algorithm. Normally this is only disabled for interactive applications like telnet.

`-V` (from v1.6 or higher)	.	Bind to an IPv6 address
		Server side:
		$ iperf -s -V
		Client side:
		$ iperf -c <Server IPv6 Address> -V
		Note: On version 1.6.3 and later a specific IPv6 Address does not need to be bound with the -B option, previous 1.6 versions do. Also on most OSes using this option will also respond to IPv4 clients using IPv4 mapped addresses.

Server specific options		
`-s, --server`	`$IPERF_SERVER`	Run Iperf in server mode.
`-D` (from v1.2 or higher)	.	Run the server as a daemon (Unix platforms) On Win32 platforms where services are available, Iperf will start running as a service.
`-R` (only for Windows, from v1.2 or higher)	.	Remove the Iperf service (if it's running).

`-o` (only for Windows, from v1.2 or higher)	.	Redirect output to given file.
`-c, --client` *`host`*	`$IPERF_CLIENT`	If Iperf is in server mode, then specifying a host with -c will limit the connections that Iperf will accept to the *host* specified. Does not work well for UDP.
`-P, --parallel` *`#`*	`$IPERF_PARALLEL`	The number of connections to handle by the server before closing. Default is 0 (which means to accept connections forever).
Client specific options		
`-b, --bandwidth` *`#[KM]`*	`$IPERF_BANDWIDTH`	The UDP bandwidth to send at, in bits/sec. This implies the -u option. Default is 1 Mbit/sec.
`-c, --client` *`host`*	`$IPERF_CLIENT`	Run Iperf in client mode, connecting to an Iperf server running on *host*.
`-d, --dualtest`	`$IPERF_DUALTEST`	Run Iperf in dual testing mode. This will cause the server to connect back to the client on the port specified in the -L option (or defaults to the port the client connected to the server on). This is done immediately therefore running the tests simultaneously. If you want an alternating test try -r.
`-n, --num` *`#[KM]`*	`$IPERF_NUM`	The number of buffers to transmit. Normally, Iperf sends for 10 seconds. The -n option overrides this and sends an array of *len* bytes *num* times, no matter how long that takes. See also the -l and -t options.
`-r, --tradeoff`	`$IPERF_TRADEOFF`	Run Iperf in tradeoff testing mode. This will cause the server to connect back to the client on the port specified in the -L option (or defaults to the port the client connected to the server on). This is done following the client connection termination, therefore running the tests alternating. If you want an simultaneous test try -d.
`-t, --time` *`#`*	`$IPERF_TIME`	The time in seconds to transmit for. Iperf normally works by repeatedly sending an array of *len* bytes for *time* seconds. Default is 10 seconds. See also the -l and -n options.
`-L, --listenport` *`#`*	`$IPERF_LISTENPORT`	This specifies the port that the server will connect back to the client on. It defaults to the port used to connect to the server from the client.
`-P, --parallel` *`#`*	`$IPERF_PARALLEL`	The number of simultaneous connections to make to the server. Default is 1. Requires thread support on both the client and server.

`-S, --tos` *`#`*	`$IPERF_TOS`	The type-of-service for outgoing packets. (Many routers ignore the TOS field.) You may specify the value in hex with a '0x' prefix, in octal with a '0' prefix, or in decimal. For example, '0x10' hex = '020' octal = '16' decimal. The TOS numbers specified in RFC 1349 are:
		`IPTOS_LOWDELAY minimize delay 0x10`
		`IPTOS_THROUGHPUT maximize`

		throughput 0x08 IPTOS_RELIABILITY maximize reliability 0x04 IPTOS_LOWCOST minimize cost 0x02
-T, --ttl #	$IPERF_TTL	The time-to-live for outgoing multicast packets. This is essentially the number of router hops to go through, and is also used for scoping. Default is 1, link-local.
-F (from v1.2 or higher)	.	Use a representative stream to measure bandwidth, e.g. :- $ iperf -c <server address> -F <file-name>
-I (from v1.2 or higher)	.	Same as -F, input from stdin.
Miscellaneous options		
-h, --help		Print out a summary of commands and quit.
-v, --version		Print version information and quit. Prints 'pthreads' if compiled with POSIX threads, 'win32 threads' if compiled with Microsoft Win32 threads, or 'single threaded' if compiled without threads.

Appendix 3

Redline
communications
AN-50 features:
• Average Ethernet rates up to 49 Mbps
• Ranges beyond 80km/50 miles
• Non line-of-sight capabilities
• 5.725 - 5.825 GHz band
• Advanced error correction achieves 99.999% reliability
AN-50
Broadband Wireless System
The award winning AN-50
Redline's AN-50 system is a high speed wireless Ethernet bridge configured for point-to-point (PTP) operation, upgradeable to point to multipoint (PMP) operation. Accommodating both backhaul and access functions, the AN-50 system is the industry's first true high performance, high capacity, multi-services OFDM platform. The RedAccess Network Management System (NMS) and web interface is remarkably easy to use and install.
The AN-50 system delivers an over the air rate of up to 72 Mbps, equivalent to 49 Mbps at the Ethernet level. With a robust non line of sight (NLOS) capability, long IF cable support for tower and high rise installations, audible antenna alignment and diagnostic capabilities for Ethernet and wireless, the AN-50 addresses the most challenging of deployment scenarios and makes installation and support easy. The AN-50 boasts software selectable channels that can be assigned during deployment on a best-performance basis.
The AN-50 system operates in the license exempt 5.725 - 5.825 GHz band and includes advanced technologies to address potential inter cell interference issues. Maximizing spectral efficiency is a critical factor that directly impacts the bottom line. In PTP mode the AN-50 rises to this challenge with a unique patented bi-directional adaptive modulation technique, automatically selecting any of eight modulation schemes (from BPSK to 64 QAM) in order to adjust to link quality degradation while providing the highest throughput for a given deployment scenario.
The AN-50 employs several techniques to address propagation anomalies associated with fixed wireless deployments, the most critical of which is multipath. The system utilizes OFDM to increase robustness in NLOS and near LOS links, ARQ to efficiently correct bit errors at the RF level, advanced error correction, and adaptive coding to achieve up to 99.999% RF link reliability. All of these features provide a robust and high performance solution that help to reduce operational costs and accelerate return on investment.
SuperQuest Award
AN-50 Product Overview

Redline communications

AN-50 System Addresses:

- Building to building connectivity for enterprises
- Backhaul for ISPs and Wireless ISPs
- High capacity surveillance and telemetry
- Facilities based service providers
- Campus networking
- Disaster recovery/Business Continuity
- Large enterprise VPN
- MTU (multi tenant units)
- Wireless private networks
- Extensions/alternatives to fiber optic networks

About Redline Communications Inc.

Redline Communications is an innovative provider of broadband fixed wireless solutions, helping companies reduce costs, extend and enhance networks and increase customer satisfaction. Redline is a leader in using OFDM technology to provide robust high speed wireless connectivity even in partial or non line of sight conditions. Redline is a principal member of IEEE 802.16 and Wimax, committed to establishing global standards for the fixed wireless industry.

Redline's products are recognized for their unique capabilities in providing backhaul links and high speed access links to urban and rural service providers. Redline has more than 5,000 systems installed by customers in over 30 countries in industries as diverse as school boards, manufacturing, internet providers, transportation, government, and health care facilities.

AN-50 Application Areas

Wireless technology has existed for many years, proving itself to be a reliable communication medium, primarily for long haul point to point applications supporting critical links for telephony and broadcast services. With the surge in broadband two way Ethernet and Internet use, fixed wireless systems are playing an even more important role in supporting today's growing network infrastructures.

AN-50 System Specifications

System Capability:	Clear, optical and non line of sight
RF Band:	5.725 - 5.825 GHz
Channel Size:	20 MHz
RF Dynamic Range:	> 50 dB
Data Rate:	Up to 49 Mbps average Ethernet rate
Max TX Power:	-20 to + 20 dBm (region specific)
Rx Sensitivity:	-86 dBm @ 6 Mbps (based on BER of $1x10^{-6}$)
IF Cable:	Maximum length up to 76 m (250 ft) using RG6U Maximum length up to 152 m (800 ft) using high-grade cable
Network Attributes:	Multiplexed IF, DC power, control (Tx/Rx, AGC, APC) Transparent bridge DHCP pass through Automatic Link Distance Ranging[2] VLAN pass through 802.3x Ethernet flow control[1] 802.1p network traffic prioritization[1]
Modulation/Coding Rates:	Adaptive Modulation (bi-directional burst to burst) auto selects; 1/2 BPSK, 3/4 BPSK, 1/2 QPSK, 3/4 QPSK, 1/2 16QAM, 3/4 16QAM, 2/3 64QAM and 3/4 64QAM
Over The Air Encryption:	Proprietary 64-bit encryption
MAC:	TDMA Concatenation / Fragmentation[1] Automatic Repeat Request (ARQ) error correction Dynamic adaptive modulation (BPSK to 64 QAM)
Range:	Over 45 km / 28 miles optical line of sight Over 80 km / 50 miles line of sight
Network Services:	Transparent to 802.3 services and applications
Duplex Technique:	Dynamic TDD (time division duplex)
Wireless Transmission:	OFDM (orthogonal frequency division multiplexing)
Backhaul Connection:	10/100 BT Ethernet (RJ45)
System Configuration:	Web interface and SNMP CLI via Telnet and Local Console
Power Requirements:	110/220/240 VAC or 48 VDC (auto-sensing single/dual), 50/60 Hz, 39 W maximum
Redundant Power:	Optional Dual AC/DC Power Supply with automatic fail over

[1]Point to Point Mode only
[2]Point to Multipoint mode only

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Appendix 4

IP Traffic - Test & Measure

IP Traffic generator and measurement tool for IP networks (IPv4): Fixed, Satellite, WLAN, PLC, mobile or cellular IP networks.

Certification of fixed and wireless IP networks

Telcos · Enterprise users · ISPs · Evaluation labs · R & D · Network equipment manufacturers

IPv4

Download trial version

Windows 98, 2000 & XP

Desktop & Laptop

'IP Traffic - Test & Measure' is a software testing tool that can run on any Windows PC (98, 2000 or XP). It can generate, receive, capture and replay IP traffic, and measure end-to-end performance and Quality Of Service over any IP network.

'IP Traffic - Test & Measure' can be used with two optional products in order to have a precise time reference and to realize measures with a high accuracy: a GPS kit provides an absolute time reference and ZClock delivers a high precision clock. This allows time stamping of IP packets sent or received, and measurement of QOS parameters over the IP network used.

'IP Traffic - Test & Measure' offers the following main modules:

- 'IP Generator' with multiple modes to generate traffic and real time statistics. A replay traffic mode is particularly useful to generate real traffic (web session, FTP, videoconferencing, ...) captured in real time with the 'Traffic Sniffer' module.
- 'IP Answering' module with real time statistics.
- 'Traffic Sniffer' to capture IP traffic in real time. Captured traffic can then be replayed by the 'IP Generator' module.
- 'Traffic Observer' for the on-line or off-line analysis of many QOS parameters (send and receive): throughputs, inter packet delay, Packet Erasure Rate (PER), packet transit delay, ... A graphical analyser with many features provides a view of IP traffic on each IP connection, and the user can configure parameters and statistics to export in a file for use with an external tool (Excel for example).
- Two operating modes: Normal or Remote (for remote control of a PC with 'IP Traffic - Test & Measure' used as server).

Omnicor

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'IP Traffic - Test & Measure' key features

IP Traffic Generator (TCP & UDP) – up to 16 simultaneous connections
Three operating modes: 'Unitary', 'Automatic' or 'Replay Traffic'

- Unitary testing mode (with independent parameters for each connection) - the following parameters can be defined: destination parameters (IP address, port number and protocol: TCP or UDP), internal or external data source generator (user file with a loop counter or user DLL), the RTT (Round Trip Time) option, the ToS (Type of Service) byte and the option to save data received on the connection. The internal data generator offers different parameters: data to send (mathematical law, packet generator or file to send), the packet size, the inter packet delay, the average throughput if needed, and the option to save data sent on the connection.
- Automatic testing mode - the user chooses the numbers of connections to activate. Starting time, data volume to send and packet size on the enabled connections can be configured.
- Replay traffic mode - to replay traffic previously captured by the 'Traffic Sniffer' module on multiple IP connections.
- Traffic statistics for each connection: sent throughput, sent packets, received packets, volume to send, remaining volume, sequence numbering errors and RTT.

IP Answering (TCP & UDP) – up to 16 simultaneous connections

- Select and define for each connection the following parameters: a specific IP address or any, the port number and protocol (TCP or UDP). For each connection, five operating modes are available: 'Echoer', 'Echoer in a file', 'Absorber', 'Absorber in a file' and 'Absorber + Generator'.
- Traffic statistics for each connection: throughput, received and sent packets, sequence numbering errors and data not echoed.

Traffic Sniffer

- Define IP filters to capture traffic at the driver level (under the TCP/IP stack). Captured traffic is time stamped in real time and saved in a file.
- An analysis tool operates on a captured traffic file to generate data traffic files used by the 'IP Generator' module.

Traffic observer: a powerful tool for on-line and off-line graphical analysis

► Two operating modes to display statistics: on-line (real time) and off-line (analysis of traffic files captured by the 'Traffic Sniffer').
► On-line statistics: IP throughput snapshot + IP throughput average + UDP / TCP throughput + inter packet delay.
► Off-line statistics : on-line statistics + Packet Erasure Rate (PER) + packet transit delay.
► Display statistics for each connection (send and receive) of the 'IP Generator or the 'IP Answering' module.
► Graphical analyser with many functions (statistical laws, user defined trigger, ...) to analyse the following parameters over the IP network used: IP throughput, inter packet delay, PER quality and packet transit delay. This analyser allows graphical correlation of several parameters and is very useful for precise analysis of characteristics and problems on the IP network used.
► With the off-line mode, you can replay traffic files by using a 'video recorder' mode (play, pause, stop) with index management.
► Export statistics in a file for the 'IP Generator', 'IP Answering' and 'Traffic Observer' modules with parameters and conditions defined by the user.

'IP Traffic - Test & Measure' and the Traffic Observer tab

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Appendix 5

Radio System Test Plan
AAC Wireless Telemetry Project
Task Order 1

1. Introduction and background

This test plan document outlines the procedures for acceptance and performance testing of the Redline Communications AN50 radio system being used provide point-to-multipoint wireless telemetry under AAC Task Order #1 by Montana State University (MSU).

MSU will test the Redline AN50 system in point-to-point (P2P) and point-to-multi-point (PMP) configurations to establish whether the radio system can meet performance requirements (e.g., range, throughput) for wireless telemetry applications associated with high-speed sensor data applications. Figure 1 show the radio configuration under consideration.

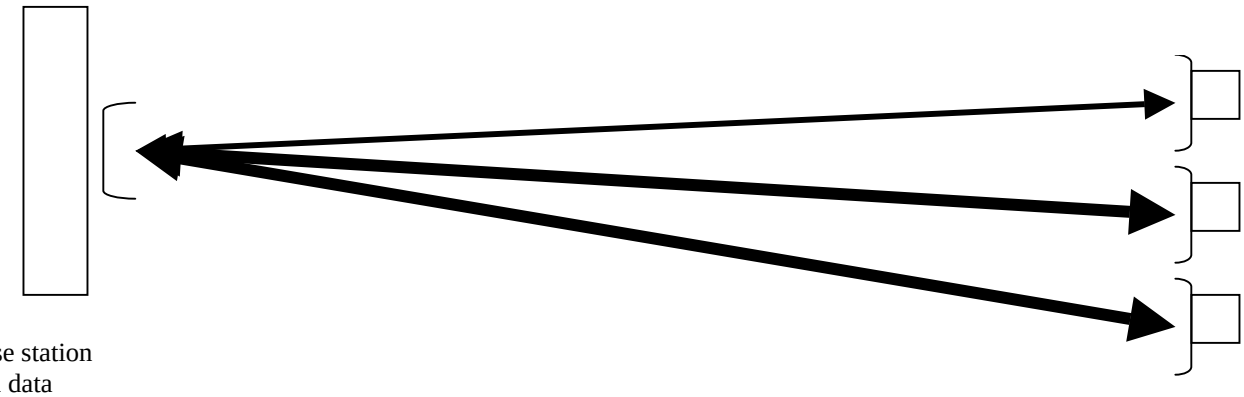


Figure 1. Radio configuration for Wireless Telemetry

The system under test consists of either one AN50 base station (BS) and one subscriber station (SS) (P2P mode) or one BS and three SSs (PMP mode). Each SS can be configured as an independent unsynchronized quasi-uniform data source emulating an acoustic sensor autonomously collecting data and relaying it to a central processing point which is emulated by the BS. The objective is to obtain an overall system throughput of greater than 50 Mb/s (aggregate of all SSs) and a range (distance between BS and furthest SS) of up to 30 miles. In the PMP mode the overall capacity of the system can be dynamically distributed among the SSs to support variable data rates as might be required by an event-driven data acquisition mode of operation.

2. Lab Test bed

MSU has constructed a lab test bed to support bench acceptance and performance testing of the AN50 radio equipment. The lab test bed is located in the AAC Tech Ranch facility consists of the following components major components.

- IP Traffic generators. MSU has procured and installed Omnicor IP traffic generator measurement software capable of generating and measuring up to sixteen simultaneous traffic streams consisting of either UDP or TCP packets. The tools measure round trip delay, lost packets, bit error rate and throughput. The characteristics (e.g., packet size, priority, inter-packet delay time, packets per second, etc.) of the traffic source can be varied on a per connection basis. The software collects, stores, analyzes and graphs the data. The Omnicor software has been installed and tested on the AAC laptop computer and on several MSU computers that will be used in the test bed. Figure 2 is a diagram of the IP traffic measurement environment.

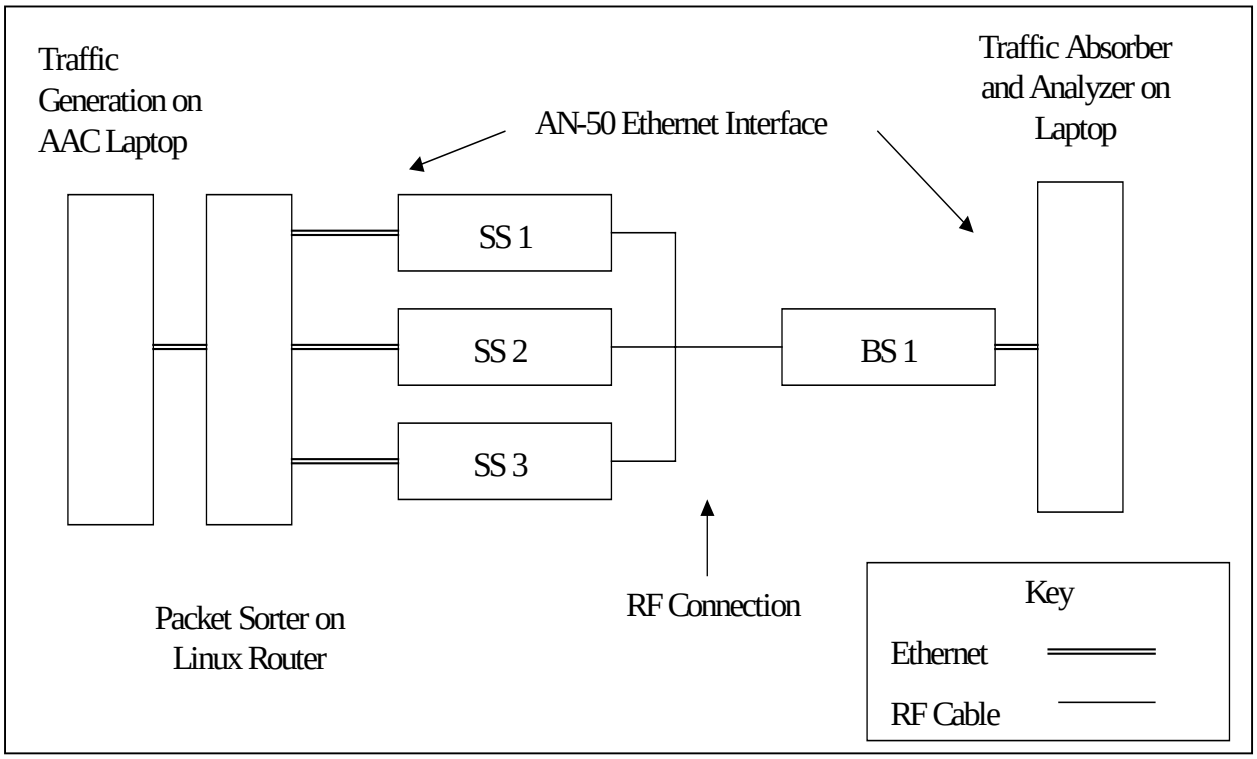


Figure 2. IP traffic generation and measurement system

- RF Test equipment. MSU has procured and assembled an RF test environment to emulate P2P and PMP configurations of the AN50 radio equipment. These components consist of high-quality RF coax cables (low insertion loss and leakage at the 5.8GHz operating frequency), fixed and variable RF attenuators (calibrated at 5.8GHz using the MSU Electrical and Computer Engineering (ECE) department RF network analyzer) and RF couplers and power splitters (1x3 and 1x2). We have also acquired, under loan from ECE, a calibrated RF noise source that can be used for noise injection for signal-to-noise ratio (SNR) performance testing. The equipment supports several configurations:
    - Single P2P connection (one BS and One SS), without or with noise injection

- Multiple P2P connections with cross talk and noise injection
- PMP connection, one BS and three SSs, without or with noise injection.

These configurations are shown in Figure 3.

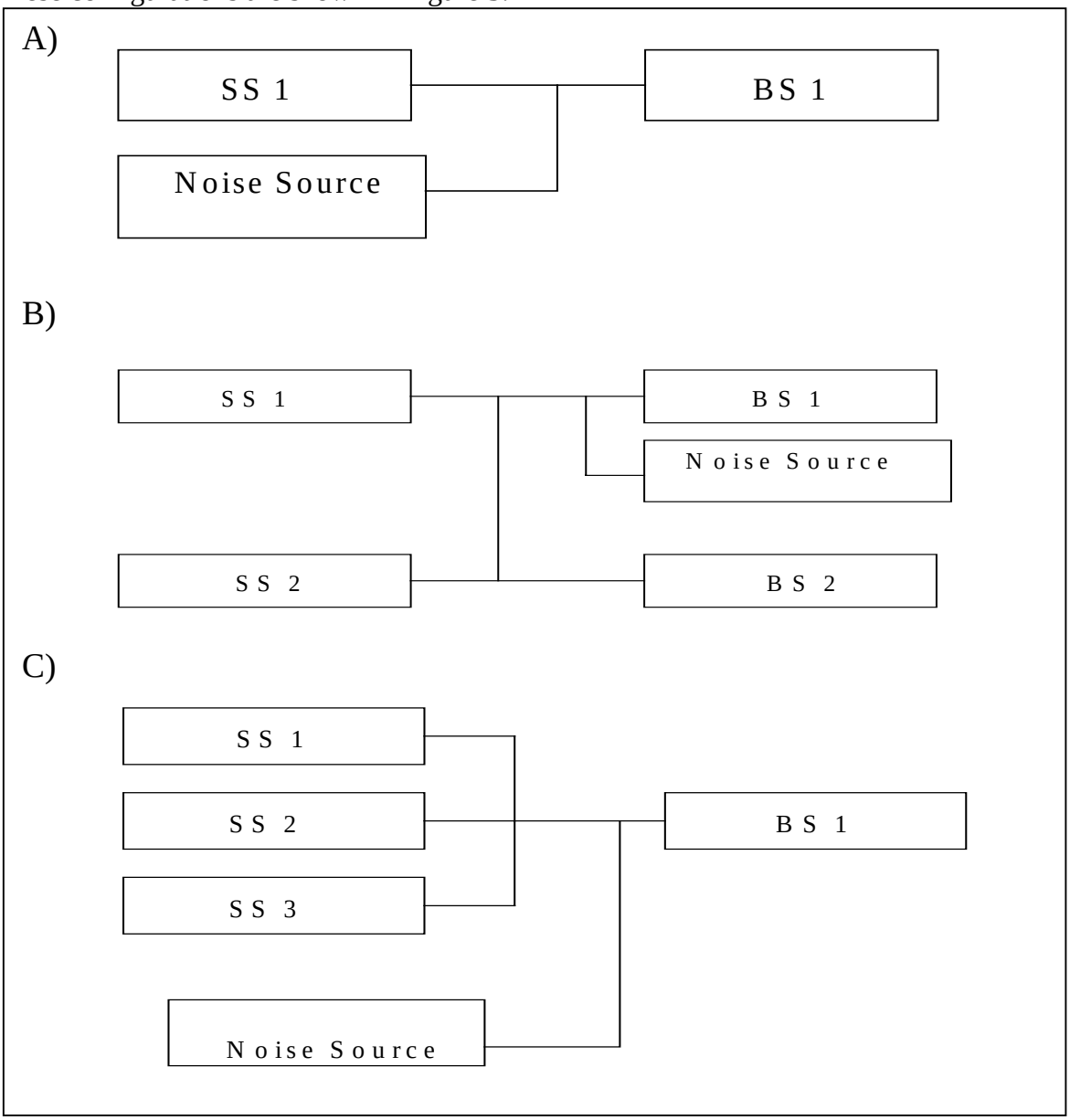


Figure 3. Testbed configurations for P2P and PMP RF performance measurements
a) P2P with noise; b) P2P with cross talk and noise; c) PMP with noise

- Data collection and analysis. We will use a combination of methods for acquiring data in the course of the acceptance and performance testing. The AN50 radios provide several internal measurement capabilities that can be addressed through the system web interface by remote computers. These include radio link parameters (e.g., transmitted and received power levels, SNR, uplink and downlink packet counts, etc.). We will use these internal measurements, listed in

Figure 4, in conjunction with the IP layer traffic data to assess system performance.

help stats – display a list with all system status & statistics values:

macaddr	Specifies the Ethernet MAC address used locally
uptime	System up time
swver	Specifies the operating software version
statscode	Specifies the status code
cableattn	The attenuation of the signal over the IF cable
cfgstat	The number of the configured stations
cfgconn	The number of the configured connections
erxpkt	Counts the number of packets successfully received locally
erxpkte	Counts the number of packet received with errors
erxpktd	Counts the number of packet received with errors
etxpkt	Counts the number of Ethernet packets transmitted
etxpkte	Counts the number of Ethernet tx packets with errors
etxpkt	Counts the number of Ethernet tx packets discarded
actwlnk	Active wireless links
txpower	The current transmit power level
rffreq	The center frequency of the channel in use

help stats id - display a list with all link status & statistics values:

ldlrate,lulrate	Downlink/uplink burst rate
ldlrssi,lulrssi	Downlink/uplink RSSI
ldlsnr,lulsnr	Downlink/uplink SINADR
ldlblk,lulblk	Downlink/uplink total blocks
ldlrblk,lulrblk	Downlink/uplink retransmitted blocks
ldldblk,luldblk	Downlink/uplink discarded blocks
ldldpkt,luldpkt	Downlink/uplink discarded packets
ldltpkt,lultpkt	Downlink/uplink transmitted packets
ldlrpkt,lulrpkt	Downlink/uplink received packets

Figure 4. AN50 Radio System web interface diagnostics

All data will be collected and archived under computer control for post-test analysis. We will use standard tools such as Matlab to analyze the data and generate reports.

3. Field test bed

We will test the radio system in the field after satisfactory completion of the lab bench tests. Our intention is to test at several ranges, over line-of-sight paths to validate the range and throughput capabilities of the system. We are making arrangements with TransAria, Inc., a Bozeman-based telecommunications service provider, to use their radio towers to perform our outdoor measurements. TransAria has radio tower sites in Bozeman, at Bozeman Pass, and in Big Timber, which will provide line-of-sight paths of about 12 and 30 miles respectively. We will test the AN50 radios in the P2P loop-back configuration using these sites and the sector antennas purchased with the radio equipment (60 Degree X 15 dBi Sectored Panel Antenna and 28 dBi 4.5 Degree 2' Flat Panel Antenna). We will work out the details of these tests in further discussions with TransAria.

4. Acceptance tests

The Redline radios were received in June 2004 and installed in the AAC TechRanch lab space. We have begun performing acceptance tests, as outlined below.

- Conformance to system specifications. We will test the radio equipment to assure that the delivered units conform to the physical and electrical specifications outlined

in Figure 5. These tests will include power consumption, transmit output power, RF frequencies and the various control functions. We will *not* test for environmental conformance. RF conformance tests (e.g., throughput versus range) will be carried out through emulation using the lab test bed and calibrated attenuators.

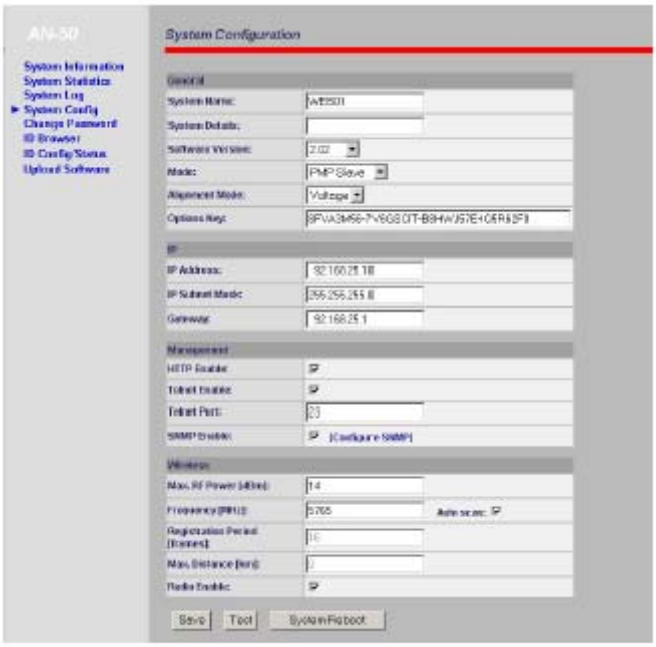
AN-50 System Specifications					
System Capability	Non-line-of-sight operations, PTP / PMP mode				
RF Band	5.725 - 5.825 GHz Band				
Channel Center Frequencies	Starts at 5735 MHz, ends at 5815 MHz in steps of 5 MHz (17 channels supported)				
Channel Size	20 MHz				
RF Dynamic Range	> 50 dB				
Modulation/Throughput	Modulation	Coding Rate	Over The Air Rate (Mbps)	Uncoded Burst Rate (Mbps)	Average Ethernet Rate (Mbps)
	BPSK	½	12	6	5.7
	BPSK	¾	12	9	8.4
	QPSK	½	24	12	11.2
	QPSK	¾	24	18	16.5
	16 QAM	½	48	24	21.6
	16 QAM	¾	48	36	31.4
	64 QAM	⅔	72	48	40.5
	64 QAM	¾	72	54	44.9
Maximum Tx Power	-20 to +20 dBm (region specific) *				
Rx Sensitivity	-86 dBm at 6 Mbps				
IF Cable	• Maximum length up to 250 ft (76m) using RG6U / 500 ft (152m) using high-grade RG11U • Maximum allowable losses at 2.5 GHz: RG6: 10 dB/30m (100 feet) at 25ºC RG11: 5 dB/30m (100 feet) at 25ºC • Multiplexed IF, DC power, control (Tx/Rx, AGC, APC)				
Network Attributes	• Transparent bridge • DHCP passthrough • VLAN passthrough				
Max Channel IDs (CID)	256 CIDs, one CID per Subscriber Station				
Provisioning	Best effort and Common Information Rate (CIR)				
Modulation	Dynamic Adaptive Modulation (bi-directional) in PTP mode and fixed in PMP mode: • BPSK • QPSK • 16 QAM • 64 QAM				
Over The Air Encryption	Proprietary 64-bit encryption				
Coding Rates	1/2, 3/4 and 2/3				
MAC	• Point to point or Point to Multipoint • Automatic Repeat Request (ARQ) error correction • Concatenation/Fragmentation				
Range	• Over 10 km / 6 miles non-line-of sight • Over 80 km / 50 miles line-of-sight				
Network Services	Transparent to 802.3 services and applications				
Duplex Technique	Dynamic TDD (time division duplex)				
Wireless Transmission	OFDM (orthogonal frequency division multiplexing)				
Backhaul Connection	10/100 Ethernet (RJ45)				
System Configuration	• Web interface				

*** Note: In some countries outside of North America, the Max. Operational Power Per Channel with a given antenna is limited in accordance to maximum allowable EIRP levels for the region.**

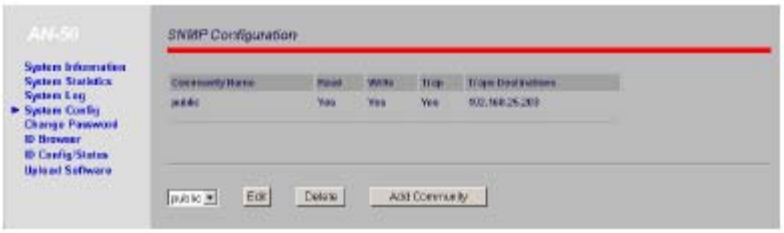
Power Requirements	Single or dual 110/220/240 VAC (auto-sensing) 50/60 Hz or –48 VDC, 39W maximum
Operating Temperature Range	AN-50 Terminal Operating Conditions: 32F to 104F / 0C to 55C T-58 Operating Conditions: -40F to +140F / -40C to +60C
Wind Loading	AN-50 Radio: 137 mph / 220 km/hr
Physical Configuration	AN-50 terminal, AN-50 Radio (T-58 Transceiver and antenna)
AN-50 Dimensions	17" x 12" x 1.75" / 431.8 mm x 304.8 mm x 44.45 mm
Component Weights	AN-50 Terminal ..... 2.0 kg T-58 Transceiver ..... 1.0 kg Vertical Mast Bracket Kit ..... 3.0 kg Vertical Mast Bracket Hardware Kit ..... 0.5 kg Cable, F Male/F Male, RG6, 100 ft 1.3 kg Antenna..... 1.0 to 27.0 kg

Figure 5 AN 50 System specifications

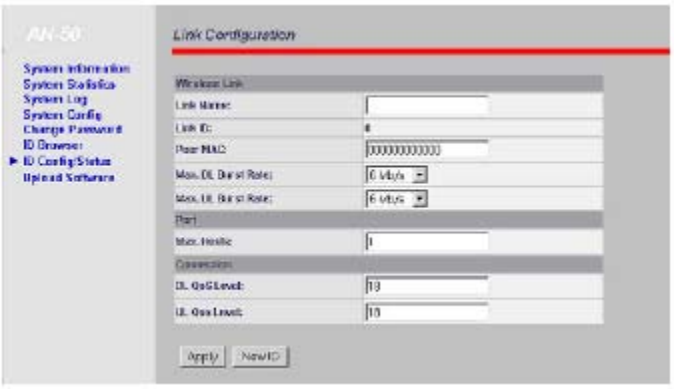
We will also test the web-based administrative interface to assure that the test points and control functions and system configuration data are all functioning as specified. The GUIs for these features are shown in Figure 6. These features include system configuration, SNMP configuration, subscriber ID and configuration, link configuration and wireless link statistics, RF error codes and software update status. Our acceptance tests will include exercising all these features, assuring that the functions work as indicated in the Redline documentation and that we can control the variables and log the data outputs via the Ethernet computer interface.



System Configuration



AN-50
System Information
System Statistics
System Log
System Config
Change Password
ID Browser
ID Config/Status
Upload Software
ID Config / Statistics
ID:
Configure
Delete
Statistics
New ID
Save IDs
Clear All IDs


AN-50
System Information
System Statistics
System Log
System Config
Change Password
ID Browser
ID Config/Status
Upload Software
Link Configuration
Wireless Link
Link Name:
Link ID:
Peer MAC:
Max. DL Burst Rate:
Max. UL Burst Rate:
Port
Max. Hostic:
Connection
DL QoS Level:
UL QoS Level:
Apply
New ID

AN-50
System Information
System Statistics
System Log
System Config
Change Password
ID Browser
ID Config/Status
Upload Software
Link Statistics
General
Link Name:
Link ID:
Peer MAC:
Active:
Link Up Time:
Link Lost Count:
Status Code:
Configured Connections:
Wireless
Downlink
Uplink
Burst Rate:
RSSI:
SINR/Nt:
Block
Downlink
Uplink
Blocks Total:
Blocks Retransmitted:
Blocks Discarded:
Packet
Downlink
Uplink
Packets Discarded:
Packets Transmitted:
Packets Received:

Error Code	Communication Error Over IF Cable	Radio High Temp. Warning	Radio Power Supply Fault	Low DC Voltage At Radio Input
0 - NO ERRORS				
1				X
2			X	
3			X	X
4		X		
5		X		X
6		X	X	
7		X	X	X
8	X			
9	X			X
A	X		X	
B	X		X	X
C	X	X		
D	X	X		X
E	X	X	X	
F	X	X	X	X

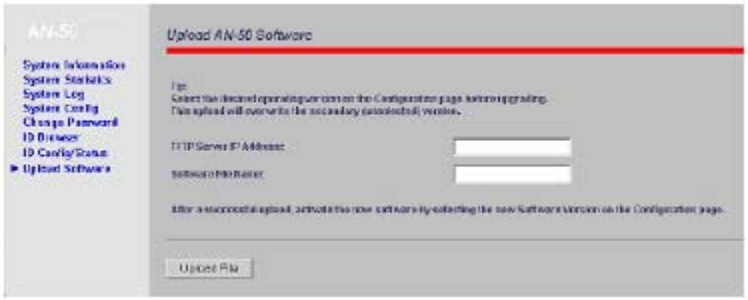


Figure 6. AN50 Web-based administrative and monitoring features

5. Performance tests

A. Throughput measurements. We will conduct a series of lab bench performance tests to measure throughput versus offered load in several configurations:

A) P2P: one subscriber station used as a reference

B) PMP: two subscriber stations

C) PMP: three subscriber stations (simulate birdstrike scenario)

In each of these tests, we will use the traffic generation software to measure actual packets received versus offered load with different amounts of traffic on the different channels (B and C) and also with different input bit rates. The objectives are to establish the efficiency of the AN50 MAC layer and to verify that the through specifications can be realized. These are given in Figure 7.

Modulation	Coding Rate	Over The Air Rate (Mbps)	Coded Burst Rate (Mbps)	Average Ethernet Rate (Mbps)
BPSK	½	12	6	5.7
BPSK	¾	12	9	8.4
QPSK	½	24	12	11.2
QPSK	¾	24	18	16.5
16 QAM	½	48	24	21.6
16 QAM	¾	48	36	31.4
64 QAM	⅔	72	48	40.5
64 QAM	¾	72	54	44.9

Figure 7. AN50 Throughput specifications

B. Throughput versus path loss measurements. We will emulate path loss using combinations of fixed and variable attenuators to test the radio system in P2P and PMP configurations:

- P2P) increase signal attenuation while observing packet loss and throughput statistics

- PMP) Same as above, but with one channel being kept at a constant power as a reference and varying the loss on the second channel.

C. Throughput versus SNR ratio measurements. We will test the sensitivity of the radio system throughput to added white noise using the RF noise injection system described above. The P2P and P2MP configurations will be tested with procedures as follows.

- P2P) Set-up a P2P link and inject noise from a broadband noise source. Increase the noise power while observing throughput and measuring packet loss.
- PMP) Set up a PMP configuration with one BS and two SSs and increase the noise in one of the BS-SS links, keeping the second BS-SS link constant as a reference, while observing the throughput and packet losses on both links.

D) Interference Testing. We will test the vulnerability of the system to interference from adjacent and overlapping RF channels. The 802.16 radio channels, shown in Figure 7, allow for channel separations that can be less than a channel width apart. Hence adjacent channels can overlap. We will test using a reference link and a potential interferer using several frequency configurations. Channel separation must be a least 20 MHz to assure that there is no frequency overlap.

Channel Frequency: specifies the operating channel of the system, within the 100 MHz available in the 5.8 GHz band. Starts at 5735 MHz, ends at 5815 MHz in steps of 5 MHz. The table below specifies the center frequencies of each permitted channel.

Frequency
5735 MHz
5740 MHz
5745 MHz
5750 MHz
5755 MHz
5760 MHz
5765 MHz
5770 MHz
5775 MHz

Frequency
5780 MHz
5785 MHz
5790 MHz
5795 MHz
5800 MHz
5805 MHz
5810 MHz
5815 MHz

Figure 7. 802.16 Radio channel assignments

- Set-up a P-P link and a P-MP link on a common set of RF cabling. Three scenarios of interest are when the radios are operating on 1) the same channel 2) partially overlapping channels 3) adjacent channels. The performance will be monitored as the received power from the interfering link is varied.